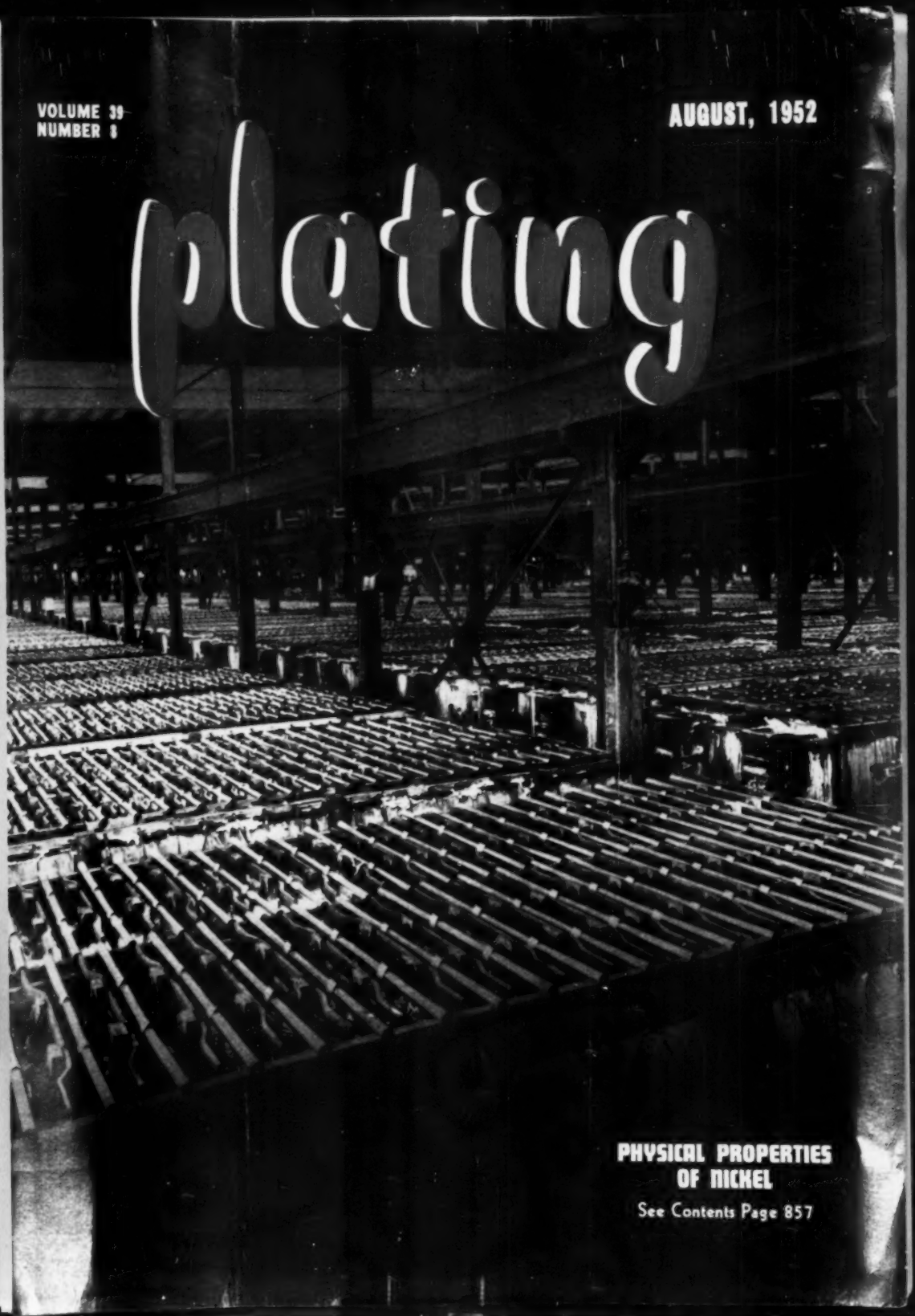
VOLUME 39
NUMBER 8

AUGUST, 1952

plating



PHYSICAL PROPERTIES OF NICKEL

See Contents Page 857

For the HIGHEST LUSTER *in* BARREL BURNISHING

scientifically compounded

CLEPO 158-A

CLEPO 158-A is a New high-luster Burnishing Compound designed for use with Burnishing Shot, Alundum or Stones.

The universal high-luster obtained with CLEPO 158-A Burnishing Compound is the result of a new development of the Clepo Laboratories.

This development eliminates the redeposition of soil on the articles being burnished and thus prevents coods from forming.

- A Clepo Service Man is available to Demonstrate CLEPO 158-A at your plant and at your convenience.

FREDERICK GUMM *Chemical Company Inc.*

538 FOREST ST,. KEARNY, N.J.

FOR FURTHER INFORMATION, USE READER SERVICE CARD: INDICATE A 1000.

NOW
REMOVE RUST FAST
WITHOUT ACIDS!

WITH

Enthone

ALKALINE DERUSTING COMPOUND 134

Do You Know What This Means?

1. Absolutely no tarnishing, etching or darkening of steel during derusting.
2. Clean and derust in one operation.
3. Reclaim rusty tools, gears and delicate threaded parts.
4. No acid or corrosive fumes around.
5. Greater adhesion of chromium, silver and nickel electrodeposits — also vitreous enamels.
6. Derust high carbon steel, cast and malleable iron and leave a white clean surface.
7. Derust coppered, galvanized and tinned surfaces without stripping the copper, zinc or tin, e. g. milk cans.
8. Pickle **fast** at room temperature.
9. Clean, derust and deposit zinc or cadmium plate **in one operation.**

Write for literature on this new discovery and also get the Enthone check list of 60 new research products for metal finishing.

METAL FINISHING PROCESSES

ENTHONE
INCORPORATED
442 ELM STREET
NEW HAVEN, CONNECTICUT

ELECTROPLATING CHEMICALS

THIS BELT ALWAYS TRACKS . . .

which definitely prevents weaving of the belt when heavy grinding pressure is applied. Proper operating tension may be maintained through a handy manual control, thus avoiding build-up of loose belt that may appear at the point of grinding contact. The 180-degree "wrap-around" facilitates proper tracking and keeps the belt constantly in position. The machine is the BADER Polisher, shown with the "Jet" head, which permits the finishing of deep, short-radius contours and fillets, and also allows plenty of clearance for projecting parts of the work.

BEHR-MANNING

BEHR-MANNING CORPORATION

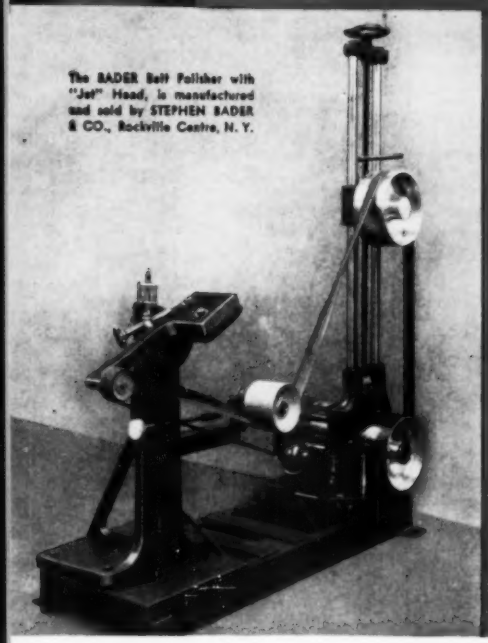
division of NORTON Company

new in belt polishing

NEVER A DULL MOMENT . . .

New equipment and new applications are constantly appearing. Here's how you can keep up with them.

BEHR-MANNING Engineers watch these developments . . . try them out . . . cooperate in working out improvements — and also initiate ideas of their own. When actual demonstration proves them of real value, your BEHR-MANNING Abrasives Engineer brings you the full story.



The BADER Belt Polisher with "Jet" Head, is manufactured and sold by STEPHEN BADER & CO., Rockville Centre, N. Y.

This is BEHR-MANNING'S service to industry—to save you time in watching for and developing new belt grinding and polishing procedures, and to show you how it would apply specifically to your operations and to your advantage. Use this service—check with your BEHR-MANNING Abrasives Engineer.

NEW INFORMATIVE PACKET

"Blueprints for Faster, Better Production" gives you a whole series of case studies on new methods and tested coated abrasive products. You'll find it interesting. Address Dept. PL-8

COATED ABRASIVES
SHARPENING STONES
PRESSURE-SENSITIVE TAPES

NORTON abrasives®

Main Office and Plant, Troy, N. Y., U. S. A.
For Export:
NORTON BEHR-MANNING OVERSEAS INC.

AMERICAN CHEMICAL PAINT COMPANY
AMBLER ACP PENNA.

Technical Service Data Sheet
Subject: PROTECTING ALUMINUM WITH ALODINE®

"ALODINE" No. 100

"Alodine" No. 100 forms an amorphous phosphate surface on aluminum which is thin, tough, durable, non-metallic, continuous with and a part of the basis metal. The "Alodine" film anchors paint, prolongs paint life, and protects aluminum exposed unpainted to the atmosphere.

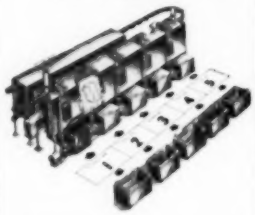
With the "Alodine" No. 100 bath at its normal temperature of 120° F., coating time by immersion approximates 1½ minutes—and by spraying, 15 to 20 seconds. Coating times and bath temperatures can be varied to suit operating conditions.

"ALODINE" No. 600

"Alodine" No. 600 forms corrosion-resistant coatings that provide excellent protection for unpainted aluminum and also make an effective paint base. This grade is recommended for use in place of "Alodine" No. 100 on aluminum parts that are to remain unpainted or to be only partly painted; and on *all* aluminum castings and forgings whether or not these are given a paint finish.

"ALODINE" FLOW SHEETS

MULTI-STAGE POWER WASHER FOR SPRAY ALODIZING



IMMERSION TANKS FOR DIP ALODIZING

PROCESS SEQUENCE

1. Clean 2. Rinse 3. "Alodine" 4. Rinse 5. Final Rinse

NOTE: Equipment can be of mild steel throughout, except the "Alodine" stage which must be of acid-resistant material.

"Alodine" No. 600 is applied at room temperature (70° to 120° F.). Recommended coating times are 3 to 5 minutes for an immersion process and 1 to 1½ minutes for a spray process.

COATING DATA	"ALODINE" NO. 100	"ALODINE" NO. 600
COMPOSITION	Amorphous phosphate.	Amorphous mixture of metal oxides and chromates.
COLOR	Depending on alloy treated, color range is from an iridescent blue-green to a dark slate gray.	Depending on time of treatment, color range is from golden iridescent to light brown.
THICKNESS	From 0.01 to 0.08 mil. No appreciable dimensional changes occur when aluminum is Alodized.	From 0.005 to 0.01 mil. No appreciable dimensional changes occur when aluminum is Alodized.
WEIGHT	50 to 300 mgs. per square foot. Optimum 100 to 200 mgs. per square foot.	35 to 50 mgs. per square foot.
SOLUBILITY	Insoluble in water, alcohol, solvents, etc. Insoluble in most dilute acids and alkalies. Moderately strong acids and alkalies which attack aluminum may penetrate the "Alodine" film and react with the underlying metal. Slightly soluble in concentrated nitric acid. Soluble in certain carbon solvents, etc.	Insoluble in alcohol, water, solvents, etc. Soluble in strong alkalis and acids.
ELECTRICAL PROPERTIES	High electrical resistance.	This coating is electrically conductive. Aluminum coated with "Alodine" No. 600 can be shielded arc welded or spot welded.
HEAT STABILITY	Dehydrated at temperatures that melt aluminum.	Dehydrated at temperatures that melt aluminum.
FLEXIBILITY	Integral with and as flexible as the aluminum itself. Can withstand moderate drawing.	Integral with and as flexible as the aluminum itself. Can withstand moderate drawing.
ABRASION RESISTANCE	Approximately 50% of that provided by chromic acid anodized aluminum.	Approximately 80% of that provided by chromic acid anodized aluminum.
CORROSION RESISTANCE	Passed superior to chromic acid anodizing. Unpainted comparable with chromic acid anodizing. Meets MIL-C-5541 and other Government Finish Specifications.	Exceeds requirements of MIL-C-5541 and even AN-QQ-A-696a (anodic films).
PAINT BONDING	Excellent. Equal to or superior to anodizing. Meets MIL-C-5541 and other Government Finish Specifications.	Excellent. Meets MIL-C-5541 and other Government Finish Specifications.
TOXICITY	Non-toxic.	Non-toxic.
BIMETALLIC CORROSION RESISTANCE	Shows good resistance against humidity or galvanic corrosion.	Shows good resistance against humidity or galvanic corrosion.

CHEMICALS ACP PROCESSES

WRITE FOR FURTHER INFORMATION ON "ALODINE" AND ON YOUR OWN ALUMINUM PROTECTION PROBLEMS.

CHEMICALS ACP PROCESSES

In This Issue

Barrel Finishing: III. Planning a Barrel Finishing Department by M. S. Shipley is a listing of the various items to be considered in the layout of a modern tumbling department, is illustrated with three figures and is the concluding section to those previously published in the December, 1951 and March, 1952 issues.

Quantitative Measurement of Adhesion of Electrodeposited Metals by Schlumpitz and Robertson describes a technique that gives promise of solving a problem for which adequate tests have not previously been devised and is continued from the July issue.

Abstracts of Convention Papers and Convention Echoes II is a continuation of Convention activities, including photographs, that were not available for publication in the July issue.

The Effect of Plating Variables on the Properties and Structure of Electrodeposited Nickel is a report on Research Project No. 9 by Zentner, Brenner and Jennings conducted at the Bureau of Standards. 60 pages of text profusely illustrated with 21 tables, 70 figures and a bibliography of over 200 references points up the enormity of the job which, with its publication, in addition to its disclosure of entirely new information, makes possible for the first time a complete single source reference on the properties of electroplated nickel.

For page numbers, see Table of Contents, page 857.

Published monthly at 5800 N. Marvine St., Philadelphia 41, Pa. Entered as second class matter July 1, 1946, at the Post Office at Philadelphia, Pa., under Act of August 24, 1916. Subscriptions: Domestic and Canada, $4.00 for 1 year, $7.00 for 2 years 50c per copy; Foreign, $8.00 per year, $1.00 per copy.

EASE OF CONTROL means faster production to Electrite. Above, Plant Superintendent J. Rodriguez racks up cadmium-plated aircraft parts. A G-E step-voltage control, obtainable for any requirement of voltages and amperes, is within arms reach.

Electrite Co. reports "No maintenance, steady production with G-E rectifiers"

SAYS "G-E PLATING RECTIFIERS ARE SIMPLEST, LOWEST-COST SOURCE OF PLATING CURRENT."

"We plate and anodize helicopter, radio and aircraft parts," says Mr. Jack Juracich, general manager of Electrite Co., Inc., "and besides accurate plating-current control, we need uninterrupted production.

"We've used G-E Metallic Rectifiers for some time now, and they have given absolutely dependable performance. They're easy to operate and need no maintenance. Also, we save money because the controls adjust power consumption to the load.

"There's no doubt that G-E Metallic Rectifiers are the simplest, lowest-cost source of plating current."

EXTREMELY LONG LIFE. Besides their many operating advantages, G-E Copper-Oxide Rectifiers are extremely long-lasting. No major part can wear out. And the copper-oxide stacks, on continuous tests, have maintained voltage stability for over 14 years! For information, write *Section 964-9, General Electric Company, Schenectady 5, N. Y.*

EASY-TO-INSTALL G-E Metallic Rectifiers are flexible, simple to maintain. Units are easily added when loads grow; no special foundations are required. Mr. Rodriguez inspecting rectifiers, says dusting is the only maintenance needed.

GENERAL ELECTRIC

Industry News

New Coated Abrasive Production Technique. A new production technique at Carborundum Company's Coated Products Division plant will set new standards of precision in the manufacture of coated abrasives. With the new setup, thickness and density of adhesive, abrasive, and final adhesive coat can be controlled with an accuracy within one per cent.

The new technique integrates five beta-ray gages, actuated by radioisotopes, into the coated-abrasive machine production line. The five gages continuously assess weight of backing, weight of adhesive, weight of abrasive, weight after pre-cure, and weight after final adhesive application on a line that travels up to 350 ft per min.

Pennsalt, Sharples Chemicals Research Groups to be Integrated. The Research Department of Sharples Chemicals, Inc., will be integrated with the Research and Development Division of the parent company, the Pennsylvania Salt Manufacturing Company, some time between June 15 and September 15.

At the same time certain organizational changes were announced. Dr. John F. Gall, currently Supervisor of Research, will become Director of the Inorganic Research Department.

Dr. John F. Olin, Director of Research for Sharples Chemicals, will be the Director of the Organic Research Department in the new organization, with Dr. George McCoy, at present Pennsalt's Organic Group Leader, as Technical Assistant Director, and T. E. Deger, Sharples Assistant Research Director, as Administrative Assistant Director.

William M. Lee and Ford R. Lowder-milk, at present supervisors of the Product Development and Process Engineering Departments, will become Directors of those departments. The Analytical Section will be given department status, with Dr. Paul A. Munter as Supervisor, and Dr. Charles E. Inman and F. E. Lawlor will be advanced to group leaders in the Organic Research Department.

Diamond Alkali Company Acquires Processes. Diamond Alkali Company, one of the nation's largest producers of basic industrial chemicals, recently intensified its activities in the metallurgical field by acquiring processes owned by Spence Metals Research Company, Pittsburgh, Pa.

The Spence Company has developed several processes using fused alkali salts for desanding of both ferrous and non-ferrous castings, and the cleaning and descaling of stainless steels.

In the future the cleaning materials will be known by the name of "Diamond Descaling Salts".

Harry R. Spence, owner and president of the Spence company, has been retained by Diamond as a consulting expert in the field.

United Chromium and Its Advertising Agency Celebrate 25 Year Association. United Chromium, Incorporated, New York, and its advertising agency, Rickard and Company, Inc., New York, recently celebrated the 25th anniversary of their association.

The United Chromium-Rickard association began in 1927, shortly after the founding of the former company.

New DuLite Plant. The Du-Lite Chemical Corporation has just completed the transfer of all operations to its new plant on River Road, Middletown, Conn.

The new quarters include 8,500 sq ft of production area, ample laboratory and quality control space, and modern offices.

Wyandotte Features Radioactive Research at A. E. S. Convention. Continuous demonstration of a Geiger counter as applied to radioactive investigation of metal cleaning proved to be a popular feature at the Wyandotte Chemicals booth at the recent A. E. S. Industrial Finishing Exposition.

WANTED

Sales-man with following in conventional and bias buff line. Salary plus commission and quarterly bonus plan. All territories open. Replies held in strict confidence.

P-852-A, PLATING
415 Broad St., Newark 2, N. J.

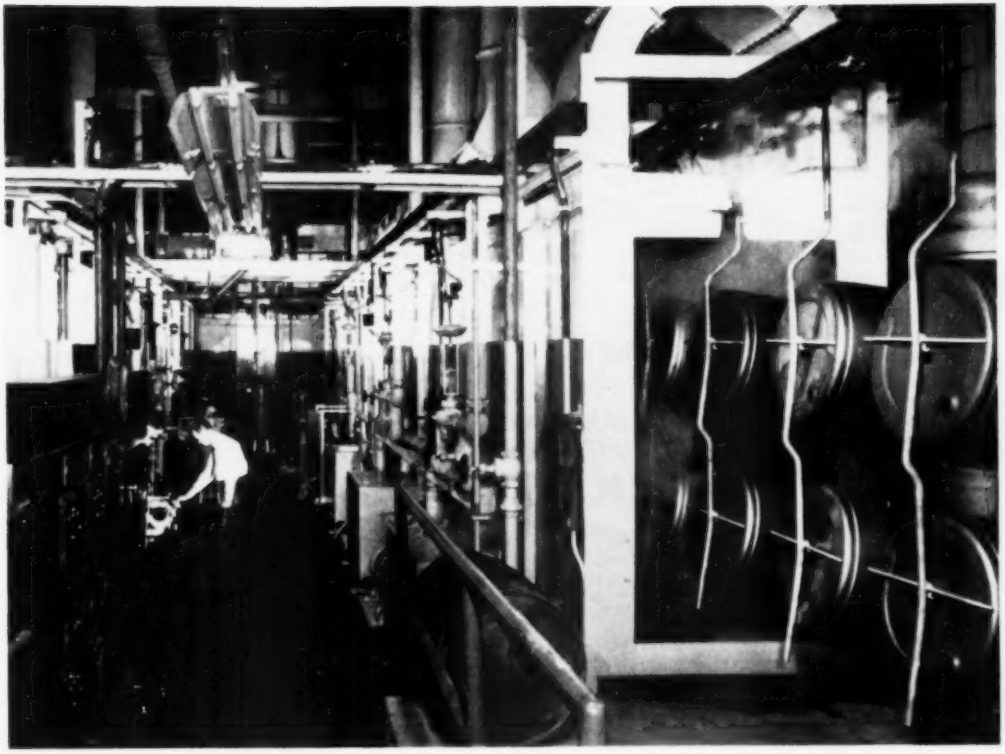
Rubber Protected Equipment For Electroplaters

Let ARCO engineers assist you in converting to the "Diaphragm" method of plating.

• For complete details ask your jobber or write for this Diaphragm booklet.

IN HOUSTON
ARco RUBBER PROCESSORS
4033 HOMESTEAD ROAD
HOUSTON • TEXAS

AUTOMOTIVE RUBBER CO., INC.
8601 EPWORTH BLVD • DETROIT 4, MICHIGAN



Choose the right cleaner for your spray wash Operations

PENNSALT CLEANERS designed to keep pace with Mechanized Cleaning Production

You will agree, no doubt, that mechanized, high speed production of finished metal parts is here to stay. And one of the mainstays of this kind of production is the continuous spray-washing machine.

Pennsalt has been at the fore in developing and supplying the exact cleaner for a given situation in any number of spray-cleaning needs. For instance: steel, brass, copper, aluminum . . . removing cutting oils, quench oils, drawing compounds, general soils.

Pennsalt Metal Processing men are trained to serve *your* requirements right in the plant. We've got the products (see list below), and we've got the technical service you want. To get either, call or write Metal Processing Dept., Pennsylvania Salt Manufacturing Company, *East:* 1000C Widener Building, Philadelphia 7, Pa., *West:* Woolsey Building, 2168 Shattuck Ave., Berkeley 4, Calif.

Pennsalt Chemicals

A BETTER START FOR YOUR FINISH

PENNSALT CLEANER 30 / **PENNSALT CLEANER 32** — concentrated, anhydrous alkalies based on *fused* ingredients, full of "mileage" and soil-suspending power.

PENNSALT CLEANER A-10 — for aluminum and other non-ferrous metals. Efficient, won't etch or stain light metals.

PENNSALT CLEANER EC-51 — Emulsion cleaner — does a superior spray cleaning job, helps make alkaline cleaners go further. EC-51 is a new *rust-inhibiting* cleaner for use in spray cleaning lines where the processing cycle is interrupted.

Industry News

The display contained six metal discs which rotated in front of an amplified Geiger counter. The discs had been soiled with radioactive stearic acid and four of them had been electrocleaned with different materials. Graphs etched into the lighted plastic background of the booth gave performance data on the efficiency of the cleaners used.

Additional Enthone Distributing Facilities. New manufacturing and distributing facilities in eight Western states are announced by Enthone, Inc., New Haven, Conn., through the L. H. Butcher Company, Los Angeles, which has recently been granted an exclusive license to manufacture products in Los Angeles to serve the Pacific Coast states and British Columbia. This new relationship brings to the Western metal finishing industry more expeditious and economical service on Enthone materials which the Butcher organization will distribute throughout Washington, Oregon, Idaho, California, Nevada, Utah, Arizona, and New Mexico.

Beckman Instruments, New Chicago Location. The Midwest Offices of Beckman Instruments, Inc., have recently moved to a new location at 7445 W. Belmont Ave., Chicago 34, Ill.

This Chicago office is under the direction of Mr. George Kincaid, who has had extensive background in the field of instrumentation. A graduate of Northwestern University, he has been with Beckman Instruments since 1946.

Seminar Slated for Engineering Profs. The third annual seminar in industrial instrumentation will be held for professors of engineering in Philadelphia, August 18 to 22, it was announced by the Industrial Division of the Minneapolis-Honeywell Regulator Company.

The five-day program is designed to familiarize the faculty of engineering schools with recent advancements in industrial processes and the attendant development of automatic instrumentation, and will also include discussions of mutual problems of engineering colleges and the instrument industry.

The seminar will be held in the company's training school in Philadelphia.

Low-Cost Removal of Annealing Scale from 20-mm Shell Rings. The Magnus Chemical Company of Garwood, N. J., carried out tests in its plant scale laboratory which have resulted in a radical reduction in the cost of descaling the rings for 20-mm shells for a large producer of these parts.

Tests indicated that when a Magnus inhibited acid cleaner was used in a tumbling barrel, results would be perfectly satisfactory without the use of any stones or other abrasives.

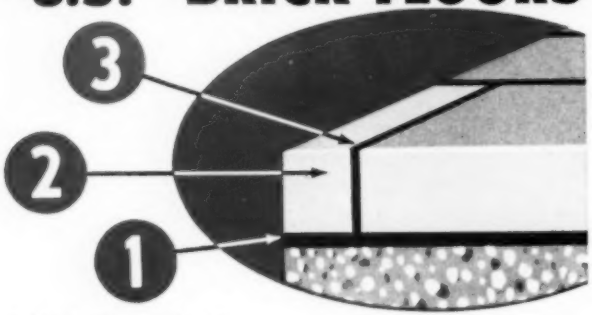
The operation at the customer's plant has been on a routine basis for some time now, with descaling in batches of 150 lbs., in runs of 15 minutes at 40 rpm.

The Metal Spray Corporation, Milwaukee, Wis., is celebrating its 18th year in business with the addition of 15,000 sq ft to its shop facilities. According to P. G. Dennison, President, it has developed and perfected techniques for building up worn dimensions and applying corrosion-resistant finishes on all types of metal products and equipment.

Cincinnati Cleaning and Finishing Machinery Company, Ironton, Ohio, has appointed **C. E. Holmes,** 831 N. 20th St., Birmingham, Ala., to represent it in Alabama, Tennessee, Georgia, Louisiana and Mississippi. He comes to Cincinnati with a background of more than fifteen years in metal cleaning and finishing, and will maintain his office at his present Birmingham location.

Consulting Services. The formation of the Nathaniel Hall Company with office and laboratory at 239 Waverly Ave., Brooklyn 5, N. Y., has been announced by Mr. Nathaniel Hall who will continue to provide consulting services in the fields of metal finishing, electrodeposition and allied processes.

Low Initial Cost — Negligible Maintenance
Protection Against *BOTH* Acids and Alkalies
in "U.S." BRICK FLOORS



A "U. S. Triple Construction" Corrosion Resistant Brick Floor provides complete protection against acid and alkali attack for practically an unlimited number of years — usually without maintenance expense of any kind.

First, an impermeable membrane of U. S. Stoneware's "RESILON" is applied over a 4" to 6" rigid sub-base. Chemically-resistant, nonporous, and flexible, Resilon protects the subfloor against acid seepage. Then split or full size "USSCO" Acid Brick (depending on the load) are buttered with "DURISITE" Cement and laid with joints $\frac{1}{16}$" to $\frac{1}{8}$" thick.

"USSCO" Acid Brick are dense, strong, resistant to erosion and spalling. Accurately shaped to lay tight and flat. "DURISITE" Cement sets quickly by chemical action — resists *both* acids and alkalies, as well as oils, greases, solvents and water. Completely nonporous, it bonds brick tightly with wafer-thin joints. Durisite is nontoxic, safe for workmen to use, and stable in storage.

YOUR OWN MASONS CAN LAY A "U.S. TRIPLE CONSTRUCTION" FLOOR

We will provide the materials for your own workmen to install a "U. S. Triple Construction" Floor, or if you prefer, we can handle the installation of the complete floor.

Write for this free book!

Detailed construction drawings showing approved methods of building floors, trenches, gutters, tank and motor supports, etc., with full technical data, photographs and case histories. Ask for Bulletin AB-17.

413C

U. S. STONEWARE
AKRON 9, OHIO

PROCESS EQUIPMENT DIVISION

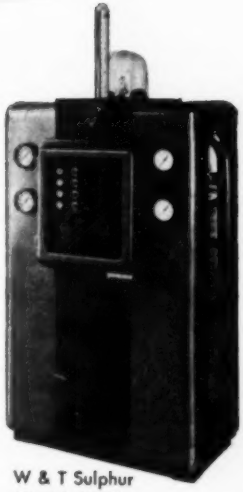
treat

TOXIC CHROMIUM WASTES

by **REDUCTION**

Chromium wastes, because of their toxicity and high color, are a problem for industry and an annoying source of stream polution.

Reduction of toxic hexavalent chromium wastes to the trivalent form with sulphur dioxide, and subsequent precipitation with alkali, has become widely accepted in the plating industry. Wallace & Tiernan offers not only the equipment for feeding sulphur dioxide but also the experience of many installations to successfully carry out the reduction process.



W & T Sulphur Dioxide Feeder

CYANIDE WASTES

Wallace & Tiernan's service to the metal finishing industry also includes experience and equipment for effective destruction of cyanide wastes by alkaline chlorination. Automatic control equipment assures complete cyanide destruction with minimum chemical costs.

Write today for additional information on Wallace & Tiernan equipment for the reduction of toxic chromium wastes with sulphur dioxide and the oxidation of cyanide wastes by alkaline chlorination.

WALLACE & TIERNAN COMPANY, INC.

CHLORINE AND CHEMICAL CONTROL EQUIPMENT
NEWARK 1, NEW JERSEY • REPRESENTED IN PRINCIPAL CITIES

S-78

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BRASS PLATING BY TRUE BRITE

NEW Free Bulletin on brass plating is now ready. Write or call for your copy.

Test Brass Thickness the new, easy way. Insure uniform plate and avoid rejects. True Brite Brass Thickness Testing is as simple as the cadmium and zinc thickness dropping tests but uses a special reagent.

No shortage of Brass plating chemicals here. True Brite Brass Makeup Solution and True Brite Brass Maintenance Solution are ready for immediate shipment. Simplify your brass plating by using these complete additions.

Copper Concentrate will solve your copper cyanide shortage. Now ready for immediate shipment in any quantity at prices you can afford.

TRUE BRITE CHEMICAL PRODUCTS CO.

P. O. Box 31, Oakville, Conn.

Practical Products for Practical People

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chromium chemicals bearing

this trademark

are preferred by leaders in the metal finishing industry

MUTUAL CHEMICAL CO. OF AMERICA — NEW YORK N.Y. — SINCE 1845 — REG. U.S. PAT. OFF.

CHROMIC ACID

SODIUM BICHROMATE

POTASSIUM BICHROMATE

MUTUAL

CHEMICAL COMPANY OF AMERICA

270 Madison Avenue • New York 16, N.Y.

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Society News

A. S. T. M. 50th Anniversary Meeting

The 50th Anniversary Meeting of the A. S. T. M. held in New York the week of June 22nd set a new high in attendance with 2,606 registrants. Seventy-five new specifications were approved for publication and 165 papers were presented. Present at the President's Luncheon were representatives of about 150 technical and scientific societies, including President Franklyn J. MacStoker of the A. E. S.

The National Instrument Conference and Exhibit to be held in Cleveland, September 8-12, will be the largest and most comprehensive meeting ever arranged by the Instrument Society of America.

Floor plans and details on the show have just been mailed from ISA Headquarters, 921 Ridge Avenue, Pittsburgh 12, Pa., to several hundred companies which have a priority on the choice of space because they exhibited at previous shows. Mailings to other companies which have expressed an interest in the exhibit will be sent out at expiration of the priority period.

Symposium in India

A symposium on electroplating and metal finishing was held March 7 and 8 at Jamshedpur under the auspices of the National Metallurgical Laboratory. It was organized by Dr. T. Banerjee, Assistant Director, National Metallurgical Laboratory and member of the Institute of Metal Finishing, London. This is the first attempt in India to bring the scientists interested in plating and the industrial platers together. Twenty-nine papers were read at the symposium, resulting in a lively discussion.

The symposium was inaugurated by Dr. J. C. Ghosh, Director, Indian Institute of Technology, also the Chairman for the first day when papers on theoretical aspects of plating were presented. Mr. R. Spears, Overseas Technical Representative of W. Canning & Company, Birmingham, England, presided over the second session on industrial plating. At the end of the symposium, a reviewing committee consisting of Dr. G. P. Contractor, Acting Director, National Metallurgical Laboratory, Dr. T. Banerjee, Mr. A. S. Santiago of Hindustan Aircraft Company, Bangalore, and Mr. Abindra Chatterjee of Ordnance Factory, Khamaria, was appointed to consider the possibility of establishing an Indian Society in the field of metal finishing.

At the conclusion of the meeting the delegates visited the Tata Iron & Steel Company, Jamshedpur.

METAL FINISHING SUCCESS goes back to

EXOLON

ALUMINUM OXIDE . . . RST

Tough, Lasting
ABRASIVE
with increased adhesion for the set-up wheel

Photomicrograph of EXOLON RST Polishing Grains.

● EXOLON RST is aluminum oxide fused in an electric arc furnace to form a hard, enduring abrasive. It is crushed, carefully graded, run through powerful magnetic separators, and ceramically coated to increase adhesion to set-up wheels. These chunky grains of RST assure efficiency and economy in all types of metal finishing.

Write for Literature on EXOLON Abrasives Today.

THE EXOLON COMPANY
973 East Niagara St. Tonawanda, New York

***Manufacturers of* SILICON CARBIDE *and* ALUMINUM OXIDE ABRASIVES**

ELECTRO-PLATING REQUIREMENTS

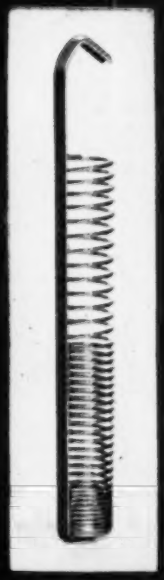
from ANODE CONTAINERS

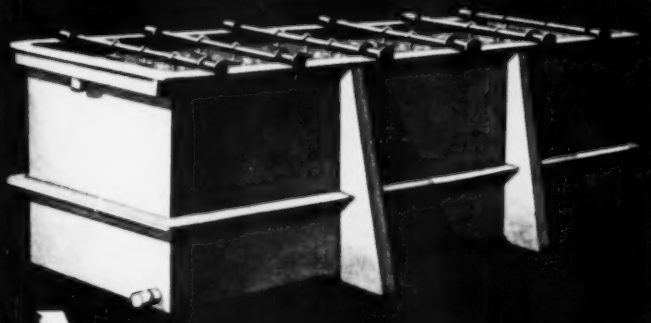
Anode production facilities here at Wagner Brothers are designed to maintain our reputation for providing none but *premium* products, the highest degree of purity in the plating industry. All types are available, promptly, in the following metals:

● Nickel, Iso-Cast Oval form, cast to give optimum grain size, any length. ● Copper, the famous Flat-Top, smooth surfaced, free from silicon, dirt and oxides; Lectrocop, pure electrolytically deposited slab form, any width or length, the lowest cost form of anode, Iso-Cast Oval, electrolytic copper molded under controls eliminating ferrous contamination. ● Zinc, in the *new standard* form, Flat-Top, easily identified, clean, cast from the purest metal. ● Tin, cadmium, available in any length in the distinctive

INDICATE A 1013.

Wagner



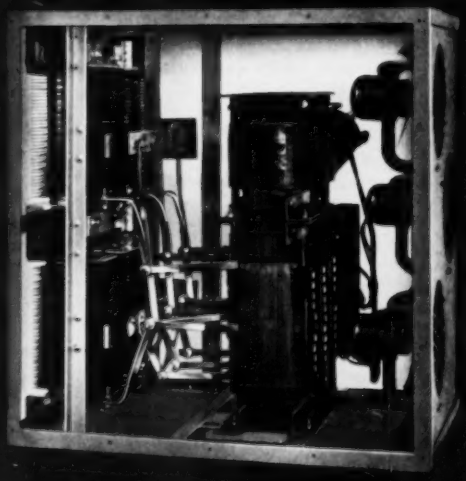


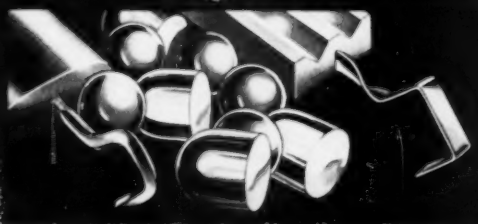
DOUBLE WELDED TANKS, all sizes, all types of linings, to your design or ours. Agitators, single or double cathode bars, as required.

ANODE CONTAINER with spline welded full length, has 4-point contact. Plate at bottom catches "nubs", permits free circulation of solution. Close spacing of coils avoids jamming of anodes. Special lengths and curved containers fabricated promptly. Standard sizes in stock.

WAGNER-TIEDEMAN RECTIFIER with back panels removed showing easy access and simplicity. Note three low-velocity cooling fans.

WAGNER ANODES in all metals are recognized as standards of the industry. Every Wagner Anode is a premium product.





to ZINC SOLUTIONS

corrugated Iso-Cast form with locked in steel contact hook. Balls are also available. ● White brass, 80% zinc, 20% copper, available in several shapes, as required.

Wagner-Tiedeman Electroplating Rectifiers have earned a place along with other Wagner premium products. Our ratings are conservative for full efficiency and safe performance. Removable panels permit quick and easy access. Ranges are from 2 to 50 volt, 750 to 10,000 or more amperes.

Wagner tanks are being incorporated in outstanding automatic and still tank operations everywhere. We're shipping to users far from our plant and the reason is simple: our tanks are built to last, our price is fair and we are ready to handle any quantity, one or one hundred, equipped with agitators and rods as required—or we'll provide your complete plating set-up, automatic or still tank.

Along with these products and the solutions, supplies and equipment for a complete electroplating system, we offer a competent sales-and-service staff. The Wagner representatives and branch managers are men with production experience and years of electroplating engineering behind them. They are backed up by an efficient laboratory and pilot plant, manned by some of the best technicians in the industry. Most important of all, you'll find every Wagner man enthusiastic about providing service to his clients and anxious to prove his ability and the integrity of the company he represents. Want proof? Pick up the phone and tell us your troubles or drop us a line at your first opportunity.

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CHICAGO • CINCINNATI • ROCHESTER

Can you afford to buy a low-priced plating filter?

In many instances the first cost of a Sparkler filter will exceed that of some other types of plating filters.

But the savings in operating cost soon will more than make up for the difference, and you will find your Sparkler a good investment both on the basis of cost and quality of performance.

For example:

★ Pre-coating Sparkler horizontal filter plates requires only about one-third the amount of filter aid used by some other filters.

★ Only a thin pre-coat is necessary, and you can get brilliant sharp clarity right from the start.

★ Intermittent operation of the filter will not break up the cake on horizontal plates. No renewal of pre-coating is necessary after a period of inactivity.

★ A wide range of fineness of filter media is possible with Sparkler filters.

★ Sparkler filters are ideal for alloy plating solutions. Non-metallic filter plates and rubber lined tanks are available when required.

These are a few of the many operating advantages that make Sparkler plating filters the most economical in labor and material cost and most satisfactory from a standpoint of filtering quality.

An extra set of plates that can be changed in a matter of minutes cuts down-time to a minimum.

Sparkler representatives in all principal cities are available for personal service on your filtering problems.

SPARKLER MANUFACTURING CO.
Mundelein, Illinois

Sparkler International Ltd.
Nieuwe Herengracht 568, Amsterdam, Holland

Kamitter & Co.
35 Chittaranjan Ave., Calcutta 12, India

Sparkler Western Hemisphere Corp.
Mundelein, Ill., U.S.A.

Personals

Edward J. Roach has joined the Wyandotte Chemicals Corporation in the Philadelphia sales district. He is a graduate of Boston College, chemistry major,

Roach

and has many years of practical, laboratory research, and sales experience in the metal finishing industry. He has been employed by the Veritas Chemical Company and the G. A. Cushman Resinous Products Company of Norwood, Mass.

Almo D. Squitero has been appointed Chief Chemist by the Hanson-Van Winkle Company, Matawan, N. J. He succeeds **Dr. D. Gardner Foulke,** recently

Squitero

appointed executive secretary of the American Electroplaters' Society, and will take over laboratory administrative duties and will supervise research and development in the fields of periodic reverse plating, graphic-arts plating, light-metal processing and other H-VW-M plating processes.

Squitero joined the Company as electrochemist in 1950, bringing with him broad experience in the electroforming and graphic-arts plating fields, beginning with graduate work at Michigan State College and continued in research and production posts in industry.

Edmund Jennings and **Philip S. Wexler** have been appointed to high level posts in Rapid Electric Company's engineering department. Mr. Jennings, formerly with the Engineering Department of Consolidated Diesel Electric Company, will supervise the mechanical design of all new products. Mr. Wexler, previously with the Long Island Lighting Company, and Ford Bacon and Davis, Inc., consulting engineers, will concentrate his activi-

With these 3 MICCRO COATINGS

YOU CAN COAT ANY PLATING RACK GIVING POSITIVE INSULATION AND COMPLETE PROTECTION THROUGH ALL PLATING CYCLES

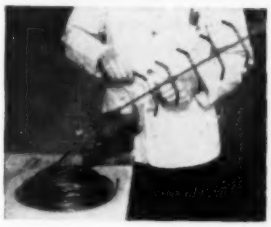
Any plant using these three MICCRO products – MICCROTAPE, MICCROTUBE and MICCROTEX – is equipped to coat any and all types of plating racks. All three products possess the same basic dielectric strength and insulating qualities. They may be used separately or together – since they will fuse and blend to form a homogeneous leak-proof coating. They may also be used to give increased life to RUBBER COATED RACKS. Throughout the plating industry these three MICCRO products have established highest records of performance and economy.

1 MICCROTAPE

An extruded tape ¾ inch in width, .012" thick in center with tapered edge of .005" (an exclusive feature). Permits much smoother overlapping, closer fit in grooves and around shoulders. Quickly applied – no heat sealing necessary. Has high dielectric strength, remains tough and permanently elastic. Miccrotape may also be used to repair rubber coated racks.

2 MICCROTUBE

An extruded tubing with the same physical and insulating characteristics as Miccrotape. Speedily applied to straight and bent contact wires, also round splines. Will fuse with Miccrotape into a perfect leakproof coating. Available in inside diameters from $\frac{1}{16}$" to 1", in thin-wall or thick-wall tubing.



3 MICCROTEX

Write for detailed bulletins of these three Miccro products.

A superior thermoplastic air-dry insulating material that meets the requirements of all plating cycles and phosphate coatings. May be dipped, brushed or sprayed. Is tough, resilient and flexible – minimizes drag-out – attains maximum adhesion without shrinkage.

MICCRO Products

Developed and Manufactured by

MICHIGAN CHROME and CHEMICAL COMPANY

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Mechanized handling in the different sequences is the basis of profitable production plating. In the MEAKER designs of automatic plating machines this handling is flexible so that adjustments and modifications are easily made to meet practically every plating requirement. Too, the simple rugged construction insures uninterrupted schedules and minimum maintenance costs.

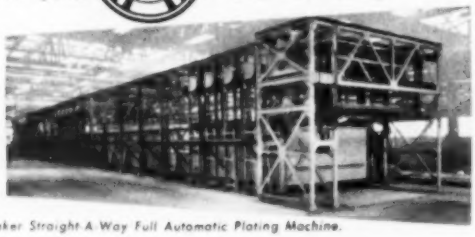
Get full particulars to meet your plating requirements from The Meaker Company, 1639 South 55th Avenue, Chicago 50, Illinois.

MEAKER

- Full Automatic and Semi-Automatic Electroplating Equipment
- Strip Steel Plating Equipment
- Wire Galvanizing Equipment
- Strip Steel Electrocleaning Lines
- Pickling Machines
- Processing Conveyors
- Motor Generators for Plating
- Rectifiers for Plating

MEAKER PRODUCTS

PLATING EQUIPMENT FOR OVER 50 YEARS



A Meaker Straight A Way Full Automatic Plating Machine.

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Personals

ties in the electrical engineering of custom-built rectifiers, automatic controls, and special applications of d-c power supplies.

Clyde Kelly (left) is named "Electroplatings' Man of the Year" as he receives the annual merit award of the Chicago

Electro-Platers Institute from Chairman **Carl F. Hansen.** Kelly, Superintendent of Superior Plating Works, Inc., of Chicago, received a gold watch in luncheon ceremonies preceding the 39th Annual Convention of the American Electroplaters' Society at the Conrad Hilton Hotel.

Dr. Robert Austin, formerly with Consolidated Engineering Corporation, Pasadena, Calif., has joined Beckman Instruments, South Pasadena, Calif., as spe-

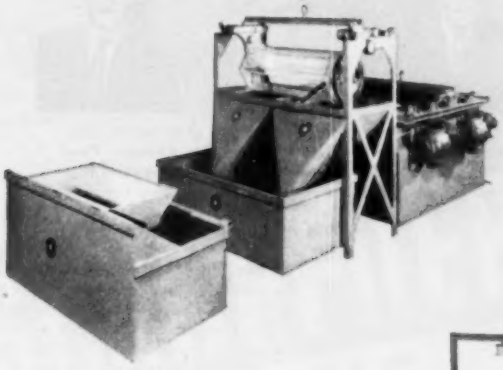
Austin **Ward**

cialist in the development of titration instruments. A native of Rexburg, Idaho, he received his Bachelor's and Master's Degrees in Chemistry at the University of Utah and his Ph.D. in Inorganic Chemistry at the University of Wisconsin.

Dr. William Ward has joined Beckman Instruments, Inc., South Pasadena, Calif., as research-staff specialist in infra-red instrument design. Dr. Ward received his Ph.D. at Ohio State University after having completed his under-graduate work in Chemistry at St. Benedict's College. He was formerly a spectroscopist with the Texas Company in its research laboratory in Beacon, N. Y.

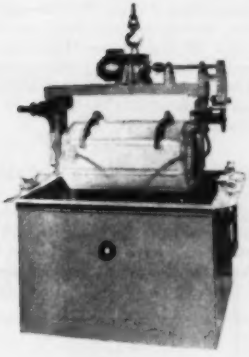
Herbert E. Hirschland has been appointed Director of Research of Metal &

CROWN PLATING BARRELS



For superior performance there's a Crown Barrel Plating Machine for the job.

A size and type for any barrel plating application.



Write for complete Barrel Machine Catalog

CROWN RHEOSTAT AND SUPPLY COMPANY

3465 N. KIMBALL AVENUE • CHICAGO 18, ILLINOIS

INDICATE A 1025.

Personals

Thermit Corporation, New York. A graduate of Dartmouth College and of Massachusetts Institute of Technology, he has been with Metal & Thermit since 1941 when he joined the company's research laboratory staff in Rahway, N. J.

Richard A. Gehr, of Schenectady, has been named sales manager of heaters and devices for the General Electric Company's Industrial Heating Department.

A 1932 graduate in electrical engineering from Pennsylvania State College, Mr. Gehr did graduate work at Penn State and later at Bucknell. He joined General Electric in 1943 as an engineer in the Industrial Heating Department. He became New York District heating specialist in 1946.

New D-Men—field service representatives of the Metal Industries Department, The Diversey Corporation, Chicago. Front row, left to right: J. J. Bennie (The Diversey Corporation, Canada, Ltd.), G. H. Heinisch and F. D. Sinclair. Back row: R. L. Shannon, Metal Industries Department Manager, and his assistant, P. A. Jackson

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SALES CLAIMS
CAN SELL
THESE
BRIGHTENERS

as well as a trial in your own plant!

Write today for a specially priced trial order of the ARP Brighteners for any zinc or cadmium plating solution. Or see your Iridite Representative.

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INCORPORATED
4004-06 E. MONUMENT STREET • BALTIMORE 5, MD

Manufacturers of Iridite Finishes
for Corrosion Resistance and Paint Systems on Non-Ferrous Metals; ARP Plating Chemicals.

Dr. Robert J. Anderson has been appointed to head the department of metallurgy at Southwest Research Institute. Dr. Anderson was awarded a Doctor of Science degree by the Massachusetts Institute of Technology, has had 35 years experience in industrial, government and educational fields, and is the author of many papers on light metals, corrosion, ferro-alloys, metal economics and physical metallurgy.

Paul Meziek has been appointed District Sales Manager for the State of Pennsylvania by Octagon Process, Inc., manufacturer of metal finishing compounds, Staten Island, N. Y.

A member of the Engineers Club, the Army Ordnance Association, the Philadelphia Chemical Club, and the American Association of Textile Colorists and Chemists, he was formerly with the Procurement Division of the Philadelphia Ordnance District, district sales manager for Charles J. Haas, Inc., Philadelphia, and eastern distributor for the L. R. Kerns Company of Chicago.

C. F. Nagel, Jr., Chief Metallurgist, was recently elected Vice-President of the Aluminum Company of America. He joined Alcoa in 1915 after he had graduated from Cornell University. In 1923 he became Assistant Director of the com-

WANTED

Electroplating Superintendent to supervise automatic zinc plating foundation facilities of large electrical equipment manufacturer. Apply, giving detailed description of education, experience and salary requirements. Reply to:

P-852-B, PLATING
145 Broad St., Newark 2, N. J.

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Look at the Record...

and you'll use...

SCHAFFNER

POLISHING BUFFING COMPOUNDS

INQUIRIES INVITED

Tell us in detail of your requirements and we will gladly quote and offer recommendations.

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MANUFACTURING COMPANY, INC.

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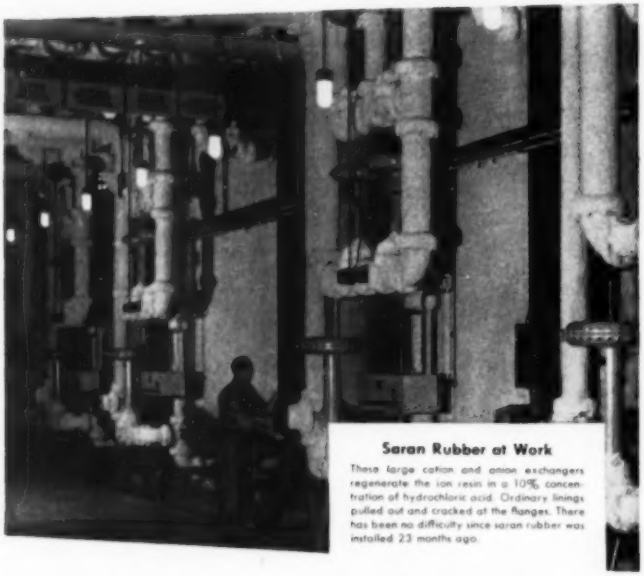
COMPOUNDS MADE IN BAR, SPRAY OR PASTE

costly corrosion checked!



Saran Rubber at Work

These large cation and anion exchangers regenerate the ion resin in a 10% concentration of hydrochloric acid. Ordinary linings pulled out and cracked at the flanges. There has been no difficulty since saran rubber was installed 23 months ago.

with SARAN RUBBER tank Lining

Industries handling, storing or transporting corrosives can lower operating costs and increase the life expectancy of costly equipment by installing saran rubber tank lining. The high degree of both chemical and abrasive resistance makes saran rubber an outstanding lining where resistance to grease, many solvents, acids and other chemicals is required.

Saran rubber can be applied easily, effectively and economically by experienced tank lining applicators located strategically throughout the country. Get in touch with an applicator today by contacting your nearest Saran Lined Pipe Company office.

for tank cars
storage tanks • tank trailers
processing tanks
production tanks

RELATED PRODUCTS

Saran rubber molded parts—stoppers, diaphragms, various-sized moldings for valves, instruments, etc.

Saran lined steel pipe—corrosion-resistant pipe that gives long-term operation with minimum maintenance.

Write to the Distributor:

SARAN LINED PIPE COMPANY

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Offices in: New York • Boston • Pittsburgh • Tulsa • Philadelphia Chicago • Portland • Indianapolis • San Francisco • Houston • Denver Los Angeles • Seattle • Cleveland • Charleston, S.C. • Toronto • Montreal

clip and send today!

Saran Lined Pipe Company
2415 Burdette Avenue, Ferndale, Michigan

Please send me your catalog on Saran Rubber Tank Lining and Saran Rubber Molding Stocks.

Name _____ Title _____

Company _____

Address _____

City _____ State _____

DOW

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Personals

pany's Technical Direction Bureau, and in 1928 Chief Metallurgist of the Fabrication Division. Since then he has been made Chief Metallurgist for Alcoa. He is also chairman of the Technical Committee and of the Research Policy Committee.

Robert A. Ruleff has been named western sales manager of Bart-Messing Corporation, Belleville, N. J. He will be located in Dayton, Ohio and will cover all of the midwestern states.

Ruleff

A registered professional engineer in the State of Ohio, Ruleff graduated from the University of Pennsylvania with a B.S. degree in chemical engineering in 1942, worked for the Westinghouse Electric Corporation as a chemical and process engineer and since 1950 has been a sales engineer for George A. Stutz Manufacturing Company of Chicago, Ill.

In answer to the many requests for the new address of Gus Soderberg, the following has been reported to Headquarters: K. G. Söderberg, Kullagardsnaegen 6, Saevedalen, Sweden.

OBITUARYS

†**Sylvester C. Pearsall**, Boston area representative for Magnuson Products Corporation for the past eighteen years and a member of the Boston Branch, died on May 13, 1952 after a brief illness.

†**Mrs. Bertha Lockerbie**, wife of John Lockerbie, honorary and Founder Member of the American Electroplaters' Society, died on June 29, 1952 of a cerebral hemorrhage following a minor operation. She will be remembered by A. E. S. members and their wives for her numerous activities in the affairs of the society and the various ladies' activities connected with it.

SURE WE STILL MAKE BENCH RECTIFIERS..

The 10,000-ampere self-contained power supply . . . the 500-KVA installation with remote control and automatic programming . . . these make exciting headlines and interesting stories.

But the humble 50-ampere bench rectifier is still the heart of many plating operations . . . important in the laboratory and on the production line.

And just as experience has taught us to make a dependable, efficient rectifier of almost any capacity, so also have we found ways of improving the smaller units—building more power, longer life, and increased usefulness into ever lighter, more compact assemblies.

So, get the facts on Rapid rectifiers the next time you need a DC power supply—of any size.

Designed to last!

Built to last!

Tested to make sure!

THE NAMEPLATE THAT MEANS *"More Power to You!"*

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distributors in major cities

Trade Literature

L—834. Finishing Equipment Catalog—J. Holland & Sons, Inc., Brooklyn, N. Y., announce the publication of their new 1952 Holland Equipment Catalog. The catalog gives data, illustrations and valuable information on the finishing equipment field, and is available at no cost to those requesting it. Use Reader Service Card.

L—835. New Periodical on Dust and Fume Control. American Wheelabrator & Equipment Corporation, 1180 S. Byrkit St., Mishawaka, Ind., is publishing a new periodical, "Dust and Fume Topics". This publication is devoted to news of how Dustube cloth tube-type Dust Collectors are handling various dust and fume control problems throughout industry.

Copies of this publication will be mailed upon request. To be placed upon the mailing list, write to American Wheelabrator & Equipment Corporation.

L—836. Bifurcator Fans—DeBothezat Fans Division of American Machine and Metals, Inc., has just issued a revised edition of their catalog on Bifurcator Fans. Specifically designed for exhausting fumes or gases which are abnormally hot, flammable or explosive, the Bifurcator is a direct motor driven fan in divided housing, with the motor mounted in a separate chamber isolated from destructive gases. Catalog is profusely illustrated and contains specifications, dimensions and certified capacities of Bifurcator Fans from 12-inch through 48-inch in diameter handling up to 45,000 cubic feet of air per minute. Copies of the catalog (number DB-4-52) can be obtained without charge by writing DeBothezat Fans Division, American Machine and Metals, Inc., East Moline, Ill.

L—837. Nielizing Corrosion Control Process—Complete data on the Nielizing Corrosion Control process are listed in the first of a news series of bulletins called "Surface Conditioning Topics". The current 16 page bulletin outlines detailed data on the surface conditioning process for ferrous metal sheets, bar stock, forgings, castings, stampings, and finished machined parts, including several illustrative photos. For your copy of this interesting booklet, use Reader Service Card.

L—838. Filtration—Standard Filter Models—A 4 page booklet PL-200 gives thumbnail description of standard models of Fulflo Filters for microscopic clarification of industrial liquids and gases, provides detailed description of Honeycomb Filter Tubes. Gives essential data on single- and multi-tube filters of capacities from 6 to 60,000 gph steel, brass, rubber lined steel and stainless steel models.

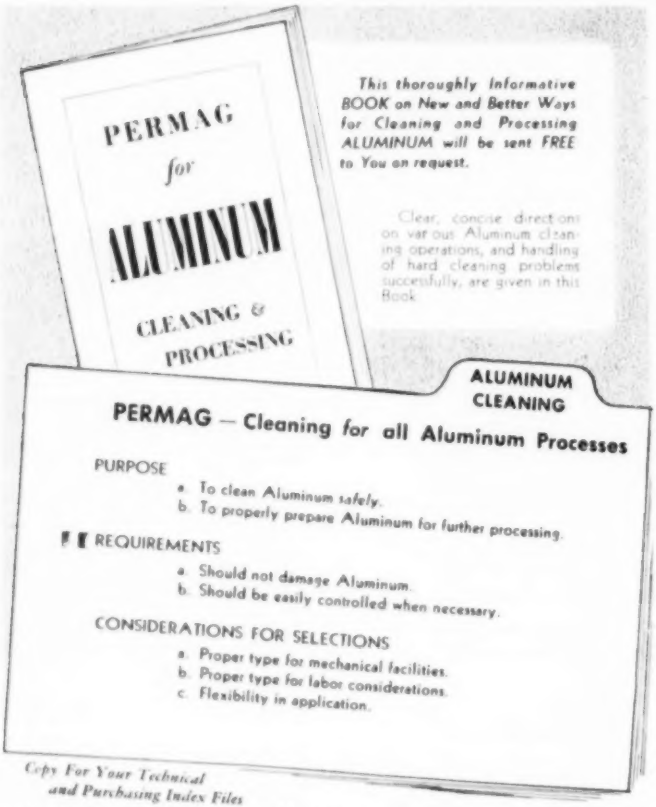
For your copy of the booklet, use Reader Service Card.

L—839. Roto Finish Case History Portfolio—A collection of editorial articles on the Roto-Finish process which have appeared in leading metalworking journals has just been released by the Roto-Finish Company, 3700 Milham Rd., P. O. Box 988, Kalamazoo, Mich. Any of the articles, or the complete portfolio, can be obtained without charge by using Reader Service Card.

L—840. Technical Guide on Corrosion-Proof Cements—A new bulletin providing technical data and catalog information on the four basic types of corrosion-proof cements has just been released by the Atlas Mineral Products Company, 72 Walnut St., Mertztown, Pa.

Included in the new bulletin are graphic charts showing the temperature range of each cement and its resistance to broad classes of corrosives. Resistance tables rate each cement specifically for 176 common chemical materials. In addition, the three principal acid-proof brick and cement constructions are also shown in association with estimating tables for each construction. For a copy of the new bulletin No. 5-2 use Reader Service Card.

L—841. Aluminum Literature and Movie Index—Reynolds Metals Company, 2500 S. 3rd St., Louisville, Ky., have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ALUMINUM
CLEANING &
PROCESSING
This thoroughly Informative BOOK on New and Better Ways for Cleaning and Processing ALUMINUM will be sent FREE to You on request.
Clear, concise directions on various Aluminum cleaning operations, and handling of hard cleaning problems successfully, are given in this Book.
ALUMINUM CLEANING
PERMAG — Cleaning for all Aluminum Processes
PURPOSE
a. To clean Aluminum safely.
b. To properly prepare Aluminum for further processing.
REQUIREMENTS
a. Should not damage Aluminum.
b. Should be easily controlled when necessary.
CONSIDERATIONS FOR SELECTIONS
a. Proper type for mechanical facilities.
b. Proper type for labor considerations.
c. Flexibility in application.

Copy For Your Technical and Purchasing Index Files

Twelfth, in the PERMAG series on Metal Cleaning and Finishing. Another important one will appear next month.

MAGNUSON PRODUCTS CORPORATION

Manufacturers of Specialized Cleaning Compounds for Industry

50 Court Street BROOKLYN 2, N. Y.

In CANADA: Canadian PERMAG Products, Ltd., Montreal, P. Q.

there's real ventilation— 24 air channels in every H-VW-M Ruff-L-Buff!

Evenly distributed ventilation, too. That means air-cooled operation even under severest use—more pressure without burning—faster cut—more composition mileage—and longer life for the buff. Air rushes into those extra large holes at the center, circulates right through the wheel, and escapes at the face. This constant flow of air—plus the fanning effect of the ruffles at the face—*eliminates excessive heat.*

Now take a look at the rest of these features: There's an extra safety factor in the rugged steel ring that anchors the cloth at the center; every buff is perfectly balanced; and that exclusive H-VW-M Red-E-To-Use Face is all set to take composition without raking or truing. Ruff-L-Buffs are available in a wide variety of types and weights for any application—to do a *better* buffing job for *you.*

Top quality buffs are just one of many results of over eighty years of constant electroplating and polishing development—a continuing policy summed up in H-VW-M Platemanship . . . your working guarantee of the best that industry has to offer—not only in buffs—but in every phase of plating and polishing.

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For full information on Ruff-L-Buffs as well as all H-VW-M buffs ask for Bulletin B-100.

Your H-VW-M combination—of the most modern testing and development laboratory—of over 80 years experience in every phase of plating and polishing—of a complete equipment, process and supply line for every need.

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H·VW·M

INDUSTRY'S WORKSHOP FOR THE FINEST IN PLATING AND POLISHING PROCESSES • EQUIPMENT • SUPPLIES

Trade Literature

just released a pamphlet listing a total of 81 pieces of literature and 8 movies on the subject of aluminum and its processing. For your copy of this index use Reader Service Card.

L—842. Corrosion Resistant Pipe and Duct Catalog—A 12-page catalog recently published by the American Agile Corporation, of Maple Heights, Ohio, describes their complete line of corrosion-resistant plastic pipe, tubing, ducting, and fittings. For your copy use Reader Service Card.

L—843. Motor, Generator and Transformer Catalog—The Electric Equipment Company, 63 Curlew St., Rochester 1, N. Y., now has in preparation a 36-page catalog showing the "World's Largest Inventory" of motors, generators and transformers in stock for immediate shipment. For a free copy of this catalog use Reader Service Card.

L—844. Heater Bulletin—A revised edition of a 12-page bulletin describing Dravo "Counterflo" Heaters, is now available without cost from Dravo Corporation, Fifth and Liberty Aves., Pittsburgh 22, Pa.

Principal addition to the bulletin, No. 523-B, is information concerning other applications besides space heating; process drying, medium temperature drying, drying vehicles after washing, and integration with air conditioning systems. Copy of the bulletin may be obtained through use of Reader Service Card.

L—845. Acid, Solvent, Alkali-Proof Equipment Bulletin—A new bulletin has just been released by the Maurice A. Knight Company, Kelly Ave., Akron 9, Ohio. It describes in detail the properties of Permanite—a furfuryl alcohol resin material used in tanks, towers, valves, fume ducts and a coating for floors of steel and wood. For your copy of bulletin No. 6 use Reader Service Card.

L—846. New Battelle Booklet—Battelle-Research in Engineering Economics is the title of a new booklet released by the Battelle Memorial Institute, Columbus, Ohio. A descriptive series of case histories of research is highlighted in the new periodical which can be obtained through use of Reader Service Card.

L—847. New Prepaint Metal Cleaner—Oakite Compound No. 31, a new highly concentrated, liquid detergent for economical prepaint treatment of metal by dipping or hand-swabbing methods is described in a special brochure available from Oakite Products, Inc., New York.

Readers wishing additional details of this new prepaint cleaner may obtain free copies of the descriptive brochure by use of Reader Service Card.

L—848. Dust Collector—A new bulletin issued and now available from Aget-Detroit Company, Ann Arbor, Mich., details specifications of dustbuster, a low cost, self-contained, bag-type dust collector. For your copy of bulletin No. 635 use Reader Service Card.

L—849. Adhesion of Hard Nickel to High-Strength Aluminum Alloy—Five pages, 10 tables and working drawings. Describes improved procedure of the well-known zincate process for electroplating on aluminum alloys. This procedure gives satisfactory adhesion and a wear resistant deposit of hard nickel on a high strength wrought zinc-aluminum alloy (Zn—7 per cent, Mg—1 per cent, Mn—0.5 per cent). Method uses a mixed acid pickle and cathodic zincate treatment which may be applicable on other aluminum alloys which are difficult to electroplate with adherent deposits. Liquid blasted surfaces average 20 per cent higher adhesion strength (46,600 psi) than polished surfaces. A modification of the Ollard test for measurement of the adhesion of deposits on sheet specimens is described. For your copy, use Reader Service Card.

L—850. Revised Catalog Describes Thermocouple Assemblies and Components—To present its complete line of standard thermocouple assemblies and parts, Leeds & Northrup Company has just published a newly revised and illustrated 44-page catalog, No. EN-S2—"Thermocouples—Assemblies, Parts and Accessories"—which not only offers the latest information on available couples and couple assemblies for general applications, but also includes an expanded section on special couples for plant and laboratory. A copy of catalog EN-S2 will be sent upon request. Use Reader Service Card.

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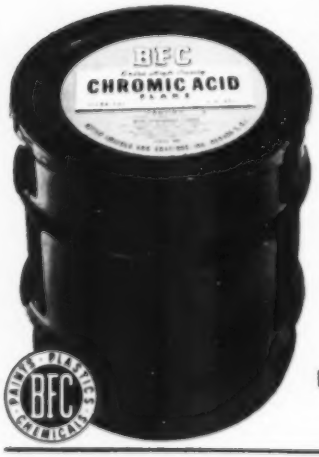

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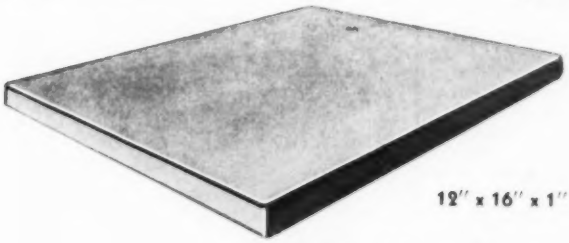

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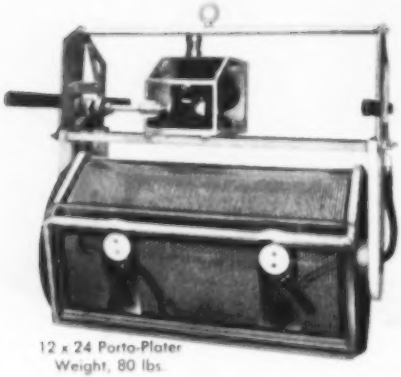
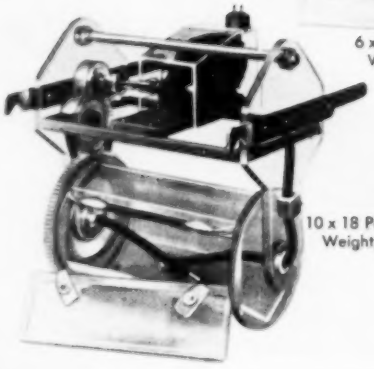
BIG Time Savers for Small Lot Plating

6 x 12 Porto-Plater
Weight, 27 lbs.



12 x 24 Porto-Plater
Weight, 80 lbs.



10 x 18 Porto-Plater
Weight, 50 lbs.

BELKE PORTO-PLATERS

FAST and EASY to use. Afford big plating barrel efficiency for small lot jobs. Complete portable plating barrel with self-contained motor drive and plug connection for use in still plating tanks or small special tanks.

Support arms rest on bus rods with V-notch cathode rod contacts for handy transfer from tank to tank. Small sizes easily transferred by hand.

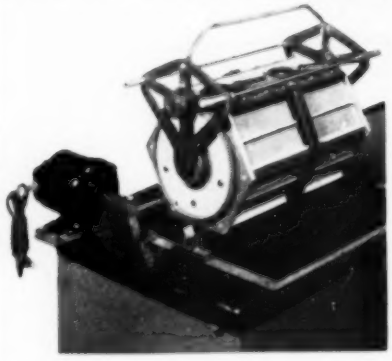
Withstand all cleaning cycles and gold, silver, rhodium, cadmium, nickel, copper, tin and brass plating at temperatures to 185° F.

Cylinder—one-piece Lucite shell bonded to ends. No obstructions or crevices to trap small pieces. Cover, cover locks, hangers, gears and bushings all High Temperature Lucite. Cover locks attached to covers—nothing to misplace or drop into the tank.

Cylinder clutch for fast and easy loading and unloading. Straight line cables with replaceable flexible cable and ball contacts. Screw-on ball contacts, easily removed for stripping.

Ask your BELKE Service Engineer or send for literature.

BELKE Small Lot PLATING BARRELS



Complete small lot plating barrel built to big plating barrel standards with self-contained motor drive and large chassis. Fits across any still plating tank. Cylinder lifts from saddles for loading and unloading.

Cylinders of BELKE Better-built construction in High Temperature Lucite, Melamine, Hard Rubber, Bakelite or Monel. Close fitting covers with attached cover locks. Flexible cable danglers and screw-on ball contacts.

Two sizes: 10x18" and 12x24" cylinders—inside dimensions. Special tanks with chassis and anode rods attached furnished at nominal cost.

Ask your BELKE Service Engineer or send for bulletin.

Belke MFG CO
947 N. Cicero Ave
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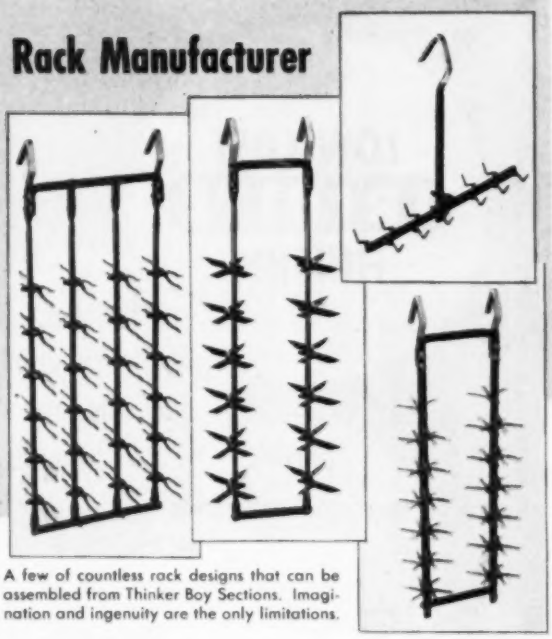
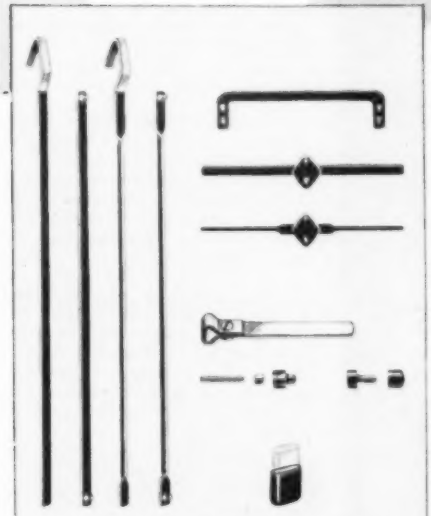
Now the World's largest Rack Manufacturer introduces

Thinker Boy Plating Rack Sections

Enable the men who think to make highly efficient racks for any plating job in a matter of minutes



A few of countless rack designs that can be assembled from Thinker Boy Sections. Imagination and ingenuity are the only limitations.



Thinker Boy — preformed rack sections — precoated with BELKE Universal Plastic and equipped with BELKE Vac-Seal Fittings. Assemble with a leakproof seal for quick, economical manufacture of the racks you need when you need them!

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No more waste and loss from inefficient Racks

Thinker Boy Sections enable you to make the racks you need **when you need them** — genuine, perfectly-formed, universal-plastic-insulated racks with removable tips. Here are a few of the many great advantages —

Efficiency — limited only by imagination and ingenuity.

Complete cleaning and plating with one racking.

Racks when you need them — you can be plating before your order for special racks could get to the factory.

Standardized dimensions — parts to match from Belke inventory.

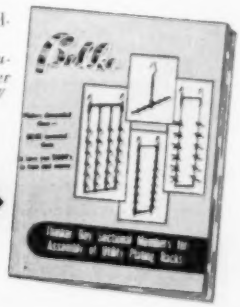
No coating problems — no coating delay.

Endless usability. Parts can be used over and over for racks of different designs. Saves thousands of dollars in rack costs.

Easy storage. Disassembled parts take little space. Eliminates the mess of old, unused racks hanging all over the ceiling.

Removable Tips. Hundreds of standard types and sizes.

New Bulletin shows how to make thousands of rack designs with Belke Thinker Boy Sections. Send for your copy NOW



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And they are easy to apply! Just a simple chemical dip for only a few seconds produces the coating.
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combine to make Iridite the most economical chromate finish you can buy. Many Iridite chemicals are packed in powder form, thus can be shipped to you in steel pails at freight savings of up to 75%! Pails take less storage space, are easier to handle, eliminate carboys, need not be returned.
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Trade Literature

L—851. Stainless Steel Process Bulletin—A 24-page booklet just published by Lindberg Steel Treating Company, 222 N. Laflin, Chicago, Ill., tells the complete story of the Malcomizing stainless steel surface hardening process, what it does, and how it works.

Subjects discussed include steel types that can be treated, suggested heat-pretreatments, selective Malcomizing, case depths, wear resistance, stability at elevated temperatures, corrosion resistance, passivation of Malcomized steels.

Seven "case histories" describe results by well-known manufacturers. For your copy of this booklet use Reader Service Card.

L—852. Dust & Fume Control Periodical—American Wheelabrator & Equipment Corporation, 1180 S. Byrkit St., Mishawaka, Ind., is publishing "Dust and Fume Topics", a new periodical devoted to news of how Dustube cloth tube-type dust collectors are handling various dust and fume control problems throughout industry.

Copies of this publication will be mailed upon request. Use Reader Service Card.

L—853. Tank Lining Booklet—Metalweld, Inc., Philadelphia, Pa. 6-page folder describes "Metalweld Plasticote", a nonporous insoluble lining that can be applied to internal surfaces of hot water generators and storage tanks to protect them against corrosion. For your copy, use Reader Service Card.

L—854. New Vacuum Metallizing Brochure—A new comprehensive brochure entitled "Vacuum Metallizing Today", has just been published by the F. J. Stokes Machine Company, Philadelphia, Pa. It describes in detail this newest low-cost coating process and how it can be applied to the surfaces of plastics, metals, glass, paper, textiles, leathers, and many other products.

Copies of "Vacuum Metallizing Today"—Catalog No. 725—and a test run of any products which manufacturers desire to metallize, may be had through use of your Reader Service Card.

L—855. Mechanical Properties of Nickel Deposits—Twelve pages, with 13 charts, 3 tables and numerous photomicrographs that show the wide range of properties that may be obtained in electro-deposited nickel by varying the solution and plating procedure. The design engineer will find data on the interrelation of ductility, strength and hardness in deposits that may be obtained in present-day rapid nickel plating solutions. The plater will find data that will help him meet the specifications of the design engineer. For your copy use Reader Service Card.

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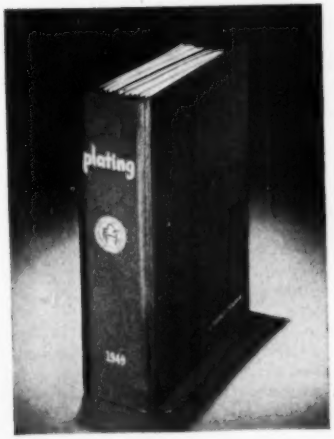

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1—2000 AMPERE—6 VOLT, G. E. COPPER OXIDE RECTIFIER.
1—GREEN SELECTROPLATER, 1800 AMPERE, 12 VOLT.
2—UDYLITE MALLORY, 1440-720 AMPERE 6-12 VOLT.

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3 HP, 5 HP, 7½ HP and 10 HP, DIVINE, HAMMOND, M. G. C., GARDNER, TWIN 5 HP & TWIN 7½ HP, ROME, and other popular makes.

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1—No. 101 PRODUCTION PIPE POLISHING MACHINE.
1—CROWN 18 x 28 CENTRIFUGAL DRYER, Steam Heat.
1—CROWN 12 x 12 CENTRIFUGAL DRYER, Steam Heat.
4—24" ROBBINS & MYERS, 2-SPEED VENTILATING FANS.
3—30" ROBBINS & MYERS, 2-SPEED VENTILATING FANS.
2—DIVINE & PORTER CABLE BACK STAND IDLERS.
1—CROWN 5-COMPARTMENT HORIZONTAL TUMBLING BARREL.
1—No. 1 RONCI LACQUERING MACHINE.
1—No. 2 RONCI LACQUERING MACHINE.

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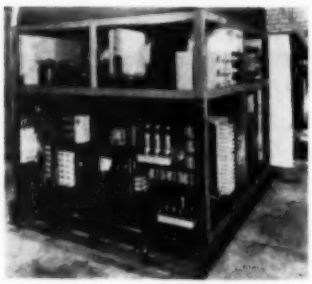
Equipment and Supplies

E—913. Sel-Rex Sealed Rectifiers—About a year and a half ago, one of the nation's largest manufacturers of automotive equipment commissioned Bart-Messing to build several 10,000 amp rectifiers that would withstand an unusually high



corrosive atmosphere. The rectifiers were built and installed and remained unopened until recently when they were opened for inspection. Absolutely no sign of corrosion dirt or dust was revealed on the selenium stacks in the interior.

The rectifiers were a new design originated by Bart-Messing, utilizing water as a cooling agent in a completely sealed internal cooler. A fan circulates the sealed-in air over copper tube aluminum-finned water circulation coils. The air does not exceed 95° F at any time. Water is obtained from normal sources and after discharge can be used for rinse purposes. Based on the excellent results of these initial rectifiers, Bart-Messing now offer completely sealed rectifiers in any size. The added efficiency, elimination of costly stack replacement and cleaning time makes its use attractive to platers. For further information, use Reader Service Card.

E—914. Cleaner for Phosphating Line—A compound designed especially for use as a pre-cleaner for steel that is to be deep drawn or extruded is announced by the Detrex Corporation, Detroit 32, Mich. The compound, Detrex 61, is used in a soak tank, and completely removes oil, grease and dirt from all ferrous parts. It possesses high wetting and penetrating properties, is very free rinsing, does not contain fatty acids or resin soaps and consequently any entrained solution will not be left with scummy deposits on their surfaces. For additional data, use Reader Service Card.

E—915. New Anode Basket—Use of scarce, costly anode metals—to the last ounce—is made possible by the new Ferrite Anode Basket now available to the plating industry through R. O. Hull & Company, Inc., 1308 Parsons Court, Rocky River 16, Ohio, Sales Agent, and its national distributors.

Expressly designed for efficient, complete solution of scrap or ball anode material, the basket may be used in nickel, copper, lead, and all cyanide baths.

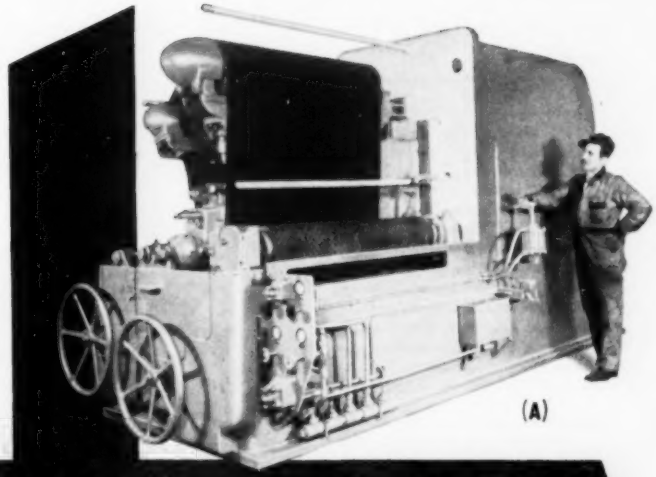
Its tapered construction is ideally suited to give continuous electrical contact to the anode mass *without* requiring replacement of "contact" anodes. Contact is made by perfectly shielded, inert graphite blades the entire depth of the basket and coupled to the anode bars. For more information, use Reader Service Card.

E—916. Heat Exchanger—The new No. 1251 Heil Heat Exchanger has been developed by Heil Process Equipment Corporation, Cleveland, Ohio, to meet the demand for an economical external type heat exchanger for heating corrosive solutions in the finishing industry. This double-pipe exchanger makes possible added space in the plating tank in addition to more even distribution of heated solution and constant circulation. Engineered in a wide variety of complete "package" standard units, the No. 1251 is easy to install and requires a minimum of time and labor for conversion from present setup or for new installation. For further information, use Reader Service Card.

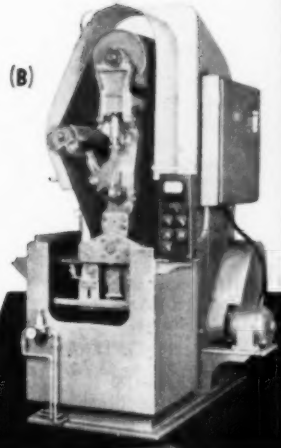
E—917. Rotary Automatic Polishing and Buffing Machine—To commemorate their 70th Anniversary, 1882-1952, the Hammond Machinery Builders, Inc., exhibited their Model C-46-40 continuous rotary automatic polishing and buffing machine with four 15 HP Model 50-84 polishing and buffing heads for the first time at an industrial show at the Industrial Finishing Exposition, Chicago, Ill.

Other Hammond Machinery was in operation with Engineers demonstrating them and offering assistance on finishing problems. For further information, use Reader Service Card.

E—918. Corrosion-Resistant Plastic Piping—A complete line of corrosion-resistant plastic piping, tubing, and ducting for use in industry, agriculture, and building is now available from the American Agile Corporation. Piping in vari-



(A)



(B)

IF THE STOCK IS FLAT
MICRO-POLISH

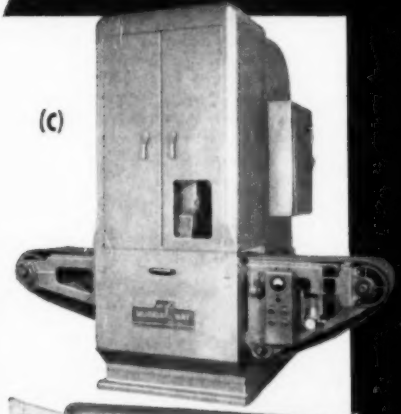
can automatically finish your job faster, better or cheaper regardless of size, shape or material.

Murray-Way, "engineered-to-the-job", Micro-Polish equipment is now being used the country over in every type of application, on every conceivable kind of material.

Micro-Polish is an amazingly versatile and consistently successful automatic polishing method useful on any job from the prepolishing of low grade steel sheet, to meet high quality job specifications, to the production sharpening and polishing of pruning tools.

Micro-Polish can precision finish any size, shape or length of sheet, strip or blanked stock in ferrous or non-ferrous metals, wood, fiber, plastic, rubber or leather, by wet or dry process.

The typical Micro-Polish equipment shown here demonstrates how Murray-Way engineers have adapted the process to individual job requirements.



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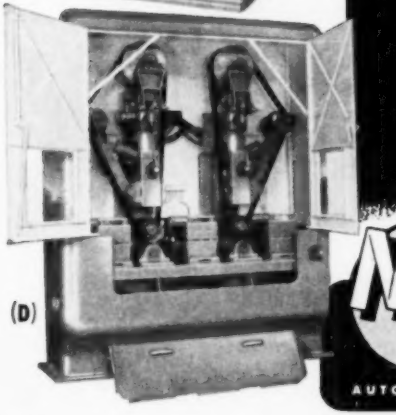

(D)

A Micro-Polish giant used in reclamation grinding of steel strip.

B One of our smaller units used in polishing narrow bi-metal stock.

C A versatile unit using belt conveyor to polish a variety of flat stampings and forgings.

D A space saver unit for polishing flat bar stock. Two heads and two grades of belt grain accomplish the complete job without rehandling.

Murray-Way engineers will gladly show you how this time and cost saving method can improve your polishing operation.

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ous grades of polyethylene, both unplasticized and rigid polyvinyl chloride, and also of the rigid rubber-resin types are furnished in diameters up to 6-inch nominal pipe size. Ducting in polyethylene is available in an assortment of standard sizes up to 22 inch diameter. The line of corrosion-resistant plastic pipe is complemented with a full supply of pipe fittings which permit simple installation of new, entirely plastic pipe lines, both of the flexible and rigid type, as well as the incorporation of plastic pipe sections and fittings into existing pipe lines. For further information, use Reader Service Card.

E—919. Disposable Processing Towels—Disposable processing towels for various wiping operations are now being offered by Kimberly-Clark Corporation in a new package under the new trademark of Litho Wipes. Soft, white and highly absorbant, Litho Wipes are made from chemically neutral cellulose fibers, uniformly felted and embossed with ribs to pick up finely divided metals and compounds. For further information, use Reader Service Card.

E—920. Airless Rotoblast Barrel—Pangborn Corporation, Hagerstown, Md., announces its new airless Rotoblast Barrel designed with several features aimed at improving cleaning operations while reducing abrasive loss. A hardened steel work conveyor chain with cast ductile iron slats which turn on the pitch line of the sprockets with the distance between

slats always the same at any point in travel prevents passage of wire or chill nails into the track of the chain where operation could be affected. When the barrel is operating, the conveyor travels upward to tumble the casting. After the cleaning operation, conveyor direction is reversed and the load is discharged into the work loader. An automatic throwout torque arm disengages barrel drive in both loading and unloading directions in case of jams. An abrasive-tight door and housing have been developed to retain abrasive within the machine and permit economical use of new types of abrasives. Two sizes are available in the new line, 6 and 12 cubic feet capacity. For further information, use Reader Service Card.

E—921. New "Tape" Solder—The Blonde Oil Company (Solder Div.), 464 Woodward Ave., Brooklyn, N. Y., announces the introduction of "Blonde Tape Solder".

This newcomer to the industrial field is a 40/60 Tin-Lead resin-fluxed solder manufactured in the form of a metallic tape, and requires no soldering iron or tools. For more information, use Reader Service Card.

E—922. Cup Grinding Wheel—Development of a new type of cup grinding wheel which retains its sharp cutting edge throughout its service life is announced by the mechanical goods division, United States Rubber Company.

The wheel has a hard shell of touch resin-bonded abrasive on a core of rapid-cutting resin-abrasive. This shell, which is 3/16 of an inch thick, resists "mushrooming" of the wheel's cutting edge. Wear occurs evenly across the entire wheel face.

Accurate grinding of hard-to-reach corners and complicated shapes is possible throughout wheel service life because of its even wear. Preparation for welding, foundry operations, finishing welds

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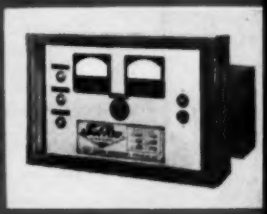

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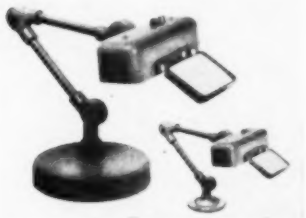
E—923. Illuminated Magnifier—Model 66SV—A new portable high intensity fluorescent fixture designed primarily for industrial inspection producing intense but cool glare-free illumination with high magnification has been announced by Stocker & Yale, Marblehead, Mass.



Model 66SV is equipped with either a 2 or 4 power lens of 2 x 4 inch dimensions and with either a heavy portable cast base or with longer arms for machine or bench mounting. The lens holder is hinged, offering the inspector complete versatility for using the light with or without the lens. Up to 500 foot candles of intense illumination is provided yet the lamp shade never gets hot. For additional data, use Reader Service Card.

E—924. Universal Pipe Supporter—Knapp Mills, Inc., has begun production of a new universal pipe supporter designed to correct a troublesome handicap in the employment of lead heating and cooling coils, as required in the processing of a variety of corrosive acids.

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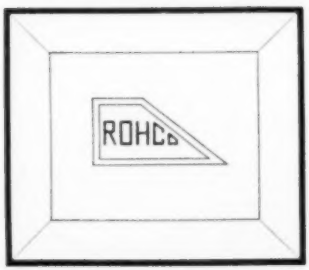

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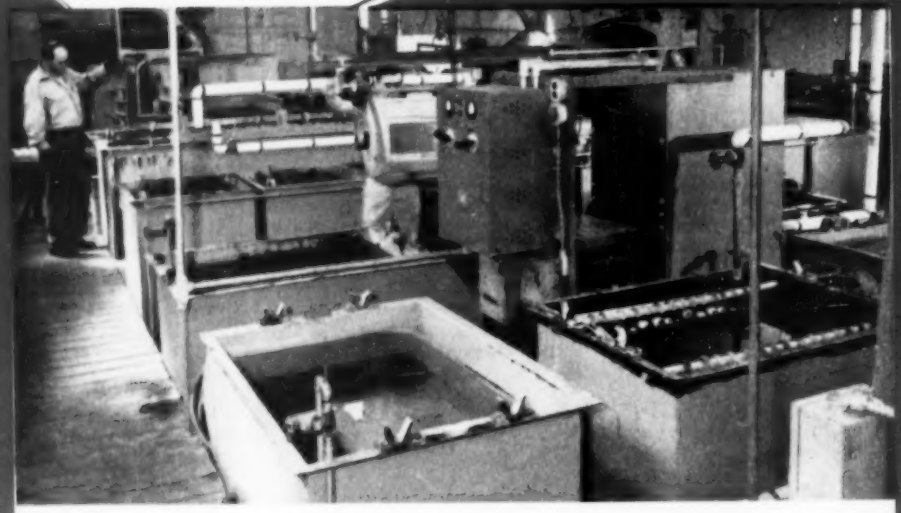

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AUGUST, 1952 VOL. 39, NO. 8

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General view of electrolytic tankhouse at the International Nickel Company, Ltd., refinery, Port Colborne, Ontario.

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Editorial

Cooperative Research

NUMEROUS INVESTIGATIONS of the properties of plated nickel coatings and the evaluation of such coatings for use in widely diversified applications have been made. With the publication in this issue of the Research Report on the work of Project No. 9 by Zentner, Brenner and Jennings, the availability of a ready single reference source covering the properties of plated nickel becomes a reality. The cooperation that made the work possible, in addition to that of the authors, runs the gamut of seven companies from the U. S. A. and England, various individual members of the A. E. S., the Society itself, the host of contributors to the Research Fund, personnel of the National Bureau of Standards, and others. Heretofore unknown properties of electroplated nickel are disclosed and results of previous investigators are confirmed and elaborated upon in this graphic example of the fruits of such cooperative research.

Al Korbelak

BARREL FINISHING

III. Planning a Barrel Finishing Department*

MORRIS S. SHIPLEY

President, Industrial Supplies & Equipment Company, Greenwich, Conn.

Introduction

The following discussion covers the essential points which should be considered in the physical set up of a barrel finishing department, exclusive of the equipment itself, which has been dealt with in Part II of this series.

Most of the items are applicable to all such departments, but some are not essential for small installations. Before deciding against any one, however, it should at least be given consideration.

Monorail Hoist

An electric hoist is almost an essential for any department. It should be of the bridge crane type and should be so constructed that it will serve not only all barrels but every other unit of the department—chip bins, incoming work, outgoing work, etc.

Water Supply

Water should be piped directly to each barrel. The final connection can be either through a short piece of hose or through swiveled pipes which will discharge directly into the barrel.

If it is possible to arrange without too much expense, hot water should be available as well as cold. Soaps and compounds dissolve so much faster in hot water that cycles can often be shortened by its use.

Compressed Air

A compressed-air line, with a hose connection for each barrel, is a great time saver. It is used to blow the fine pieces of abrasive off the gasket which seals the doors just before these are clamped shut. These fine particles, if not removed, tend to spoil the door seal and eventually destroy the gasket, causing bad leaks.

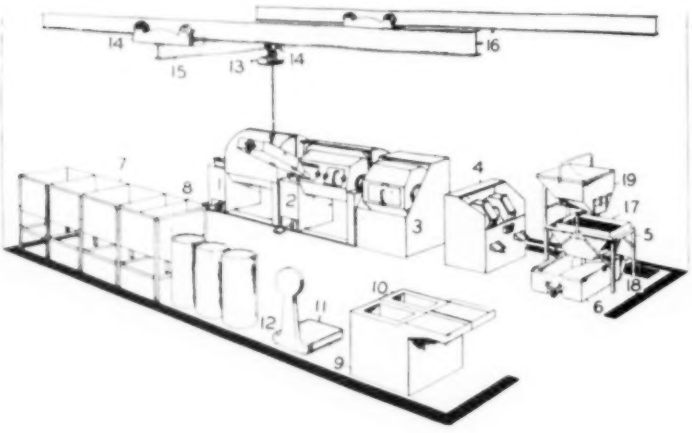


Fig. 1. Artists' view of well-planned tumbling department.

1. 60-2 Machine; 2. 48-2 Machine; 3. 32-2 Machine; 4. X-24-2 Machine; 5. Manual Separating Table; 6. Hoist Pan; 7. Chip Bin (single); 8. Chip Bin (double); 9. Water Tank (rinsing); 10. Oil Tank (rust prevention); 11. Weighing Scales; 12. Compounds; 13. 2000 lb Capacity Hoist (electric or air); 14. Bridge Crane; 15. Bridge Crane Hoist Beam; 16. Traverse Rails for Bridge Crane; 17. R. F. Screen for Separation; 18. Drain; 19. Hopper

Part I, Some Fundamentals, was published in the December, 1951 issue and Part II, Selection of Equipment, in the March, 1952 issue.

Drainage and Pitch of Floor

Modern wet-rolling techniques involve the use of large quantities of water which must be disposed of as speedily as possible. As some kind of soap or burnishing compound is almost always present and tends to make floors slippery, arrangements should be made to keep the water away from where the workmen walk, to the greatest possible extent.

For this reason, barrel-rolling departments now have the drains at the back of the barrels rather than in front. The floor is pitched from front to back. A pitch of 1/8 inch per foot is the minimum, but a pitch of ¼ inch per foot is far better.

The drain itself can be a concrete or brick trough, a foot or two back of the barrels. It should be about a foot wide and 6 inches deep.

The actual drain opening should be in the nature of a sump, with the open end of the drain pipe raised an inch or two above the bottom. This, in turn, should be divided from the rest of the trough by baffles about 2 inches high. These baffles prevent clogging of the drain pipes and permit sludge and other heavy foreign matter to settle where they can be removed periodically.

Material Storage

Burnishing compounds and cleaners are ruined if they get wet, or even damp. As they sometimes are quite expensive, care should be taken to provide dry storage space for them.

A raised platform which will keep them off the floor, placed as far as possible from the tumbling barrels, is easy to provide and entirely adequate.

Parts Storage and Handling

Many an otherwise well-planned department is badly hampered because both unfinished and finished work clogs the working space and slows operations.

In laying out the department, ample space should be provided for storage of both unfinished and finished work—out of the way of workmen. Furthermore, bottlenecks should be avoided. Aisles and doorways should be wide enough to permit easy movement of parts and supplies, in and out.

Personnel

Barrel finishing has graduated from being a hit-or-miss process, but all too often management still thinks of it as merely a strong-back job. Actually, the man in charge of a modern barrel-finishing department, whether it be one barrel or one hundred, has just as much responsibility as the foreman of the machine shop or the plating department. He must be intelligent and have an inquiring mind so that he will profit by his own experience and that of others, and he must have an interest in the development of sound techniques for the work at hand.

It is obvious, therefore, that the selection of the proper man for the job is just as important as the selection of the proper equipment.

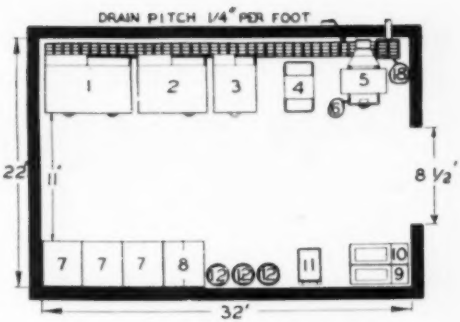


Fig. 2. Plot plan of tumbling department

The amount of labor required varies from plant to plant. To a large extent it depends on variety of work involved and length of runs. Normally, the longer the run, the more barrels one man can handle.

As a general average, one man can take care of four barrels. If the cycles are short and media must be changed often for different types and sizes of parts, one man may be needed for every three barrels. Conversely, if runs are long and only a few different parts are involved, one man may be able to handle five, six, or more barrels.

Conclusion

This article, actually, is a check list of things to be thought of in laying out the sort of department that will pay dividends. None of them should be overly expensive and none are difficult.

Whereas many of the points may have seemed rudimentary, it is hoped that this outline will help newcomers to the field to plan properly from the start and so avoid costly revamping at a later date.

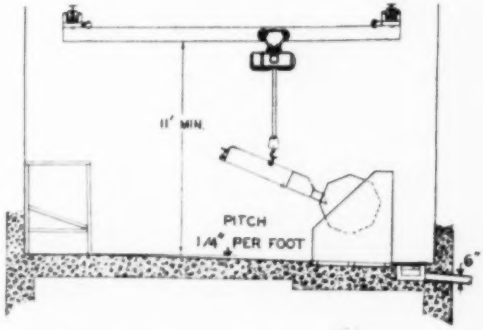


Fig. 3. Cross section of department showing pitch of floor, location of drain, and the height of bridge crane

QUANTITATIVE MEASUREMENT OF ADHESION OF ELECTRODEPOSITED METALS*

H. C. SCHLAUPITZ† AND W. D. ROBERTSON‡

(Continued from the July, 1952 issue)

Modified Nodule Method for Testing Adhesion

Inasmuch as the foregoing results indicated that the Ollard type of adhesion test does not meet the required specifications, an attempt was made to design a test that might more nearly approach the "ideal". Brenner's nodule method[5] was adopted in principle but modified to eliminate high stress concentration at the base of the nodule and to provide symmetry across the interface. This was accomplished by electroforming identical concentric cylindrical nodules on both sides of the electroplated base metal, which gives a miniature tensile specimen with the electrodeposited base metal sandwiched between the two nodules. The specimen is shown schematically in Fig. 6. The material of the nodule should have a flow curve and a fracture curve at considerably higher values than those of the deposit and base metal in order that the nodule material does not fail prematurely but transmits the load to the deposit and the base metal in such a manner that they be subjected to a state of stress approaching "hydrostatic tension". Furthermore, the deposit and base metal should be as thin as possible so that plastic deformation is minimized.

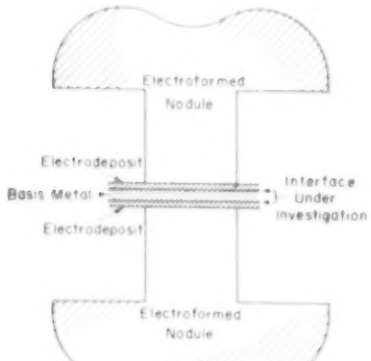


Fig. 6. Schematic view of an adhesion-test specimen with electroformed nodules for gripping the electrodeposits

One of the major problems associated with the modified nodule adhesion specimen was the development of an electroforming fixture in which the two nodules would be exactly in line on opposite sides of the test specimen to avoid eccentric loading. Also, the fixture must outline the nodule sharply on the base metal and not permit plating solution to penetrate onto the specimen surface underneath the fixture. The fixture which was finally developed, and which worked satisfactorily in both respects, was made of Lucite and is shown in Fig. 7. With this fixture five nodules are electroformed simultaneously on each plated specimen. They are 1/16 inch (1.6 mm) in diameter and have a stem 1/16 inch (1.6 mm) in height. The head is 5/32 inch (4.0 mm) in diameter and is plated to a thickness of approximately 1/16 inch (1.6 mm). For the initial experimental work, nickel nodules were electroformed from a chloride bath containing $NiCl_2 \cdot 6H_2O$, 300 g/l (40 oz/gal); H_3BO_3, 30 g/l (4 oz/gal), which had been purified according to standard procedures[6].

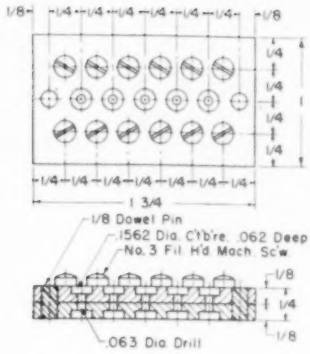
Because it is necessary to have the base metal as thin as possible to restrict deformation, preliminary work was conducted on annealed copper foil 0.003 inch (76 μ) thick, with a grain size of 0.025 mm.

---

*Abstracted from a thesis presented by H. C. Schlaupitz in partial fulfillment of requirements for the degree of Master of Engineering, Yale University, 1951.

†R. Wallace & Sons Manufacturing Company, Wallingford, Conn.

‡Hammond Metallurgical Laboratory, Yale University.



Material: 125 Thick Lucite

Fig. 7. Fixture for depositing nodules on foil specimens

The shape of the specimen cut from the foil is shown in Fig. 8. The foil test specimen extends beyond the Lucite fixture at both ends for current connections and for better definition of the current density. The technique followed in preparing a test specimen is as follows:

(1) The foil is treated in the manner prescribed by the purpose of the test, for example, by electropolishing and plating.

(2) The prepared foil is inserted in the Lucite plating fixture, and after proper alignment the screws are tightened and covered with a plating-stop-off coating.

(3) The foil is chemically activated to receive nickel plate and carefully rinsed with water, care being taken not to trap bubbles in the counterbored holes.

(4) Nickel nodules are formed at 24 asf (2.6 amp/dm^2), 130–140° F (55–60° C) and *p*H 4.0–4.5. Under these conditions it takes about four days to build up the nodules. The appearance of the specimen after electroforming is shown in Fig. 9.

(5) The screws are removed and the Lucite dissolved in acetone.

Because of the small size of the specimen and the nature of the test, axiality of loading is very important. Consequently, grips (Fig. 10) similar in principle to those used by Burke for tensile loading of magnesium single crystals[17] were employed. Axiality is insured by transmitting the load through flexible piano wire from the cross-head of the tensile-testing machine.

The results obtained on five nodules electroformed

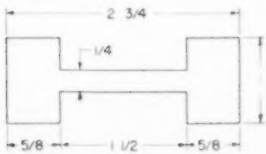


Fig. 8. Dimensions of foil specimen, in top view, for nodule adhesion test

TABLE II. ADHESION OF MODIFIED NODULES DEPOSITED DIRECTLY ON COPPER FOIL

Specimen	Fracture Stress psi	Location of Fracture
1a	46900	Entirely in copper foil
1b	44100	Entirely in copper foil
1c	46100	Entirely in copper foil
1d	31400	Entirely in copper foil
1e	46800	Entirely in copper foil

on one specimen of copper foil are presented in Table II. The copper foil was first electropolished in phosphoric acid, which reduced the thickness to 0.0025 (64 μ). The nickel nodules were then plated directly on the copper foil without an intermediate deposit.

In all cases the fracture occurred entirely in the copper foil. This indicates an adhesive strength between the electrodeposited nickel and the copper foil greater than the fracture strength of the copper foil. Furthermore, the load did not go through a maximum but rather increased continuously to fracture.

The reproducibility of the fracture strengths for three of the nodules is very good, and the average is 46,600 psi (32.8 kg/mm^2). This value is in agreement with that presented by Gensamer[18] for the fracture strength of copper wire, 48,000 psi (33.8 kg/mm^2). It is interesting to compare the value with the technical tensile strength of annealed copper, which is approximately 30,000–35,000 psi (21–25 kg/mm^2). The remaining two nodules exhibit fracture strengths approximately 5000 and 15,000 psi (3.5 and 10.5 kg/mm^2) respectively below the above-mentioned average. The reason for this large deviation is not entirely clear. It may be that axiality of loading was not obtained in spite of precautions taken, or perhaps these deviations represent local variations in the fracture strength of

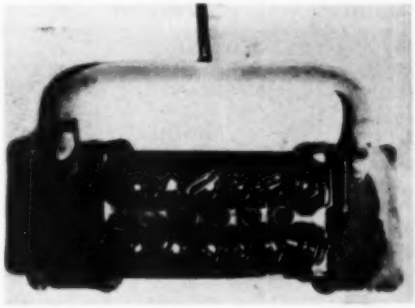


Fig. 9. Appearance of nodule-test specimen after removal from electroforming bath

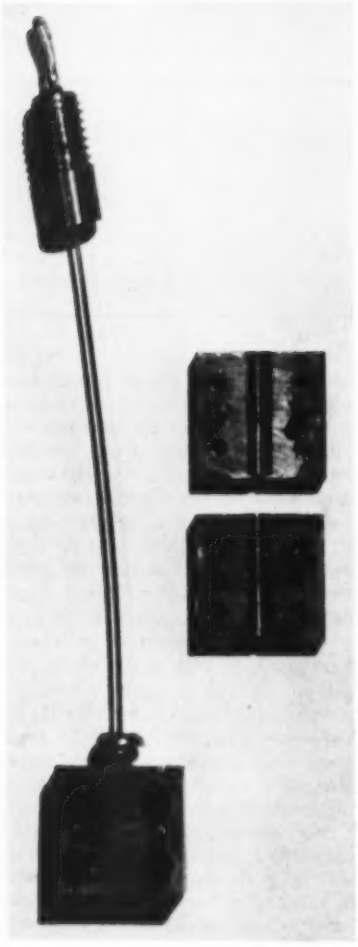


Fig. 10. Grips employed in tensile testing of nodule adhesion specimens

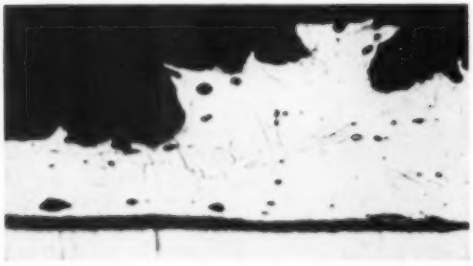


Fig. 11. Cross section through fractured copper foil, 700X. Above black line, copper foil; below black line, nickel nodule

the copper foil. Further investigation is indicated.

Examination of the fracture in the copper foil under the microscope indicated that little plastic flow had occurred during the tensile testing. Photomicrograph of the fracture of specimen 1c is shown in Fig. 11. It should be observed that grains, twin boundaries, and grain boundaries extend to the fracture surface without any sign of distortion. Another feature which indicated that little plastic flow had occurred in the nodule during the testing was that the final diameter of the stem after fracture was the same as the original diameter.

The foregoing results show that the general principle of the method is sound in that an approximation to the fracture strength may be obtained with little plastic deformation; furthermore, the procedure, although rather laborious, is perfectly feasible.

In a continued evaluation of the method, a limited number of tests were made to determine the adhesion of a silver deposit to copper foil, with and without a preliminary strike. After having been electropolished in phosphoric acid, one test specimen was given a silver strike at 22 asf (2.4 amp/dm^2) and the other was placed directly in the silver plating solution without a previous strike; current connections to both specimens were made previous to immersion in the silver plating solution. They were silver plated at 6 asf (0.65 amp/dm^2) to a thickness of 0.0001 inch (2.5 μ). Nickel nodules were then electroformed onto the silver plated foil. The results obtained on the two specimens of plated foil are given in Table III.

Although the data obtained on the silver plated specimens are less reproducible than those on the unplated copper foil (owing to pits in the nickel nodules) certain conclusions may still be deduced. It is evident that the adhesion of silver to copper previously treated with a silver strike is at least equal to the fracture strength of the copper itself. Without a strike, failure occurred at the silver-copper interface and at much lower values. In view of the fact that failure occurred in the nickel nodules, it is difficult to say whether or not the wide scatter in adhesion values when fracture took place at the silver-copper interface is an inherent characteristic of plating without a strike. However, the data can be interpreted to mean that the adhesion of a silver deposit to copper without a strike is unreliable.

Summary and Conclusions

The general problem of evaluating the adhesion of electrodeposits has been considered, and appears analogous to that of measuring the fracture strength of metals in the absence of appreciable plastic deformation. To conduct this type of test and to obtain significant data, it is necessary to design a test specimen incorporating (1) symmetry across the interface in question, (2) absence of local stress concentration, (3) a minimum base-metal and deposit thickness to limit plastic deformation, and (4) a means for trans-

(Continued on page 932)

project no. 9

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Physical Properties of Electrodeposited Metals

I. NICKEL

3. The Effect of Plating Variables on the Structure and Properties of Electrodeposited Nickel

I. INTRODUCTION

The electroplating industry has for years utilized metals for various purposes without realizing the extent to which each application of the metal is based upon its properties. The main properties which determine the value of a thin metallic coating, usually applied for decorative purposes or corrosion resistance, are surface appearance including color and reflectivity, hardness, abrasion resistance, ductility; and those chemical properties that determine the corrosion resistance. The properties which are of value in heavy electrodeposits, for engineering applications, as in electroforming and building up of worn parts are somewhat different. Here the important properties are mechanical, such as internal stress, tensile strength, hardness and ductility, yield strength and fatigue limit. For some special applications the electrical, magnetic and thermal properties may be important.

Just as the properties of metals can be varied considerably by metallurgical treatments, the properties of electrodeposited metals may be varied by changing the conditions of deposition. Indeed the properties of electrodeposited metals may be made to vary over a much wider range than is obtainable by ordinary metallurgical treatments. Some of the variations in properties brought about by changing the conditions of deposition are quite striking. A familiar example is the variation in hardness and brightness of chromium according to the temperature of deposition[1][2]. The following study of nickel deposits will show some equally interesting variations in properties. For example the deposit from the Watts type solution is dull in color, relatively soft and ductile; but in the presence of a relatively small concentration of organic compounds in this solution the deposit becomes bright and has the hardness and strength of cutlery steel.

The main objective of this study was to accumulate data on those mechanical properties of nickel electrodeposits which are of immediate value in engineering applications. A further aim was to collect data on other properties, such as density and electrical, magnetic and thermal properties, which may be of value in determining the suitability of nickel deposits for special applications. A subsidiary but important purpose was to correlate the physical and mechanical properties of nickel deposits with their conditions of deposition, structure and chemical composition and to show the correlations existing between the properties themselves. Unless such basic information is availo-

TABLE I. SUMMARY OF IMPORTANT PHYSICAL PROPERTIES OF NICKEL OBTAINED UNDER VARIOUS CONDITIONS OF DEPOSITION

Expt. No.	Bath Symbol	Temp. °C	C.D. amp./dm.²	pH	Composition % weight			Density, g./cm.³			Stress lb./in.² × 10⁻³	Hardness Vickers			Tensile strength lb./in.² × 10⁻³			Elongation %			Young's modulus lb./in.² × 10⁻⁶	Resistivity microhm-cm.			Magnetic properties as-deposited			
					Fe	Co	Ni	as deposited	400° C.	1000° C.		as deposited	400° C.	1000° C.	as deposited	400° C.	1000° C.	as deposited	400° C.	1000° C.	as deposited	as deposited	400° C.	1000° C.	$B_{max.}$	B_r	H_c	$\mu_{max.}$
1	A	20	5	1.5		0016	0092					173			81			14				8.03						
2		20	5	3.0								230										8.31						
3		55	0.5	3.0								104										10.00						
4		55	1	3.0								183										7.38						
5		55	2	3.0								183										8.21		8.80	5.56	3.05	55	58
6		55	5	1.5	1.31	014	0011	8.91		8.92	20	215			82	77	38	20	22	14	23.5	7.84		7.79				
7		55	5	3.0	46	0004	0001	8.92		8.91	17	202			86			29			23.0	8.00		7.98				
8		55	5	5.0		0173	0017	8.92		8.86		182			104			6				7.88						
9		55	10	3.0								275										8.43						
10		55	15	3.0								300										10.88						
11		55	25	3.0								253																
12		80	5	1.5								190			90			18				8.22						
13		80	5	3.0								222																
14	sn	55	5	3.0		0139	0011					182	122	87	88	58	37	14	42	18	25.5	7.44		7.48				
15		55	5	3.0	†							†																
16		55	5	5.0	†							†																
17	Sn(Cl)	10	1	3.0								207			78			25										
18		10	2	3.0	39	0101	0067	8.86		8.78	41	251										8.19		7.77				
19		20	2	3.0							23	322										8.63						
20		20	5	3.0								235										7.77		7.83				
21		30	2	3.0	1.37							174										8.23						
22		30	2	5.0		0123	nil								75			18										
23		30	5	1.5		0063	0007					237			105			11										
24		30	5	3.0	37	0092	nil				35	182	137	99	75	62	47	15	39	37	23.8	8.53						
25		30	5	5.0		0207	0006					185			72			19				7.78		7.68				
26		40	5	3.0								155			75			19				8.86		9.41				
27		55	0.25	3.0	1.43	0027	0038	8.90		8.39		322										9.42	9.28	9.23				
28		55	0.5	3.0	1.90	0115	0003	8.91	8.91	8.83	29	203	214	108								9.65						
29		55	0.5	5.0								218										8.58						
30		55	1	3.0	1.87						30	200			77			27			23.6	8.74						
31		55	1	5.0								210										8.42						
32		55	2	1.5								169			74			22				8.13	8.08	8.18				
33		55	2	3.0	1.07	0020	nil	8.92		8.92	27	139	138	88	56			23										
34	Sn(Cl)	55	2	5.0	1.05							201			87			17										
35		55	2	5.5		0142	0017					206			89			23										
36		55	2	5.8							81										26.3	7.85		7.71	5.73	3.08	22.1	81
37		55	5	1.0	54							162			59			26				7.86		7.62	5.67	3.00	21.0	80
38		55	5	1.5	66	0070	0005				24	190	140	102	87	58	39	28	35	25	24.1	7.76	7.74	7.66	5.75	2.83	17.4	95
39		55	5	3.0	54	023	0002	8.91		8.91	17	150	147	88	56	53	35	28	39	17		7.82		7.70				
40		55	5	4.0								145			66			25			23.7	7.94		7.88	5.55	2.90	15.8	101
41		55	5	5.0	89	034	0008				25	160			59			25				8.14		8.36				
42		55	5	5.5	43	0427	0074	8.90		8.84		220			85			25				8.10		7.62				
43		55	5	5.6		0650	0016	8.87		8.85	59	235			101			5										
44		55	5	5.8							67	400										8.01						
45		55	10	1.5								228										7.78	7.72	7.76				
46		55	10	3.0	65			8.91		8.91	15	161	144	91								7.88						
47		55	10	5.0							21	163										7.90						
48		55	15	3.0							19	180																

Expt No.	Bath Symbol	Temp. °C	C.D. amp./dm.²	pH	Composition % weight			Density (g./cm.³)			Stress lb./in.² × 10⁻³	Hardness Vickers			Tensile strength lb./in.² × 10⁻³			Elongation, %			Young's modulus lb./in.² × 10⁻⁶	Resistivity microhm-cm			Magnetic properties as-deposited			
					Co	Os	H_2	as deposited	400° C	1000° C		as deposited	400° C	1000° C	as deposited	400° C	1000° C	as deposited	400° C	1000° C	as deposited	as deposited	400° C	1000° C	B_{max}	B_r	H_c	μ_{max}
49		55	20	3.0								175										8.35						
50		55	25	1.5								254										8.19						
51		55	25	3.0	35	.0527	.0048	8.89	8.89	8.86		195										7.88		7.90				
52		55	25	5.0								200										7.91						
53		55	50	1.5								245										8.78						
54		70	5	3.0								181			65			28				7.95		7.66				
55		80	5	1.5								155			67			17							5.65	2.54	25.0	59
56		80	5	3.0	60	.0082	.0004				26	182	170	96	78	71	36	28	27	23	27.3	7.87						
57		80	5	4.0		.0089	nil	8.91			25	223			79			21				8.41						
58		80	7	4.0								183			73			21				8.08						
59		80	10	4.0		.0180	nil					185			77			23				7.88						
60		80	15	4.0								159			88			16				7.70						
61		80	20	4.0								145										7.65						
62		80	30	4.0				8.91				160										7.68						
63		80	5	5.0								152			67			21										
64		85	5	3.9								215										8.37						
65	$o8_{(11)}C_1$	30	2	3.0		.0086	.0010					205			89			10				7.66						
66		30	5	3.0							40	165			73			13				7.66						
67		55	0.5	3.0				8.91		8.80		178										7.50		7.64				
68	$o8_{(11)}C_1$	55	1	3.0				8.91		8.90		194										7.43		7.46				
69		55	2	1.5								197			70			23										
70		55	2	3.0								138			53			30				7.49		7.54				
71		55	2	5.0								205			77	59		20	28			7.51						
72		55	5	1.5							28				62			31				7.50						
73		55	5	3.0		.0110	.0001	8.91		8.91	15	142			60			31			22.3	7.44		7.41	5.55	2.77	18.4	91
74		55	5	5.0		.0366	.0036				23	192			73			23			28.4	7.41						
75		55	10	3.0								186										7.41		7.40				
76		55	25	3.0				8.91		8.91		234										7.76		7.42				
77		80	5	3.0								188			79			25				7.55						
78	Na	30	5	3.0		.0124	.0005				34	157			75			12				7.79						
79		55	2	3.0		.0042	.0008					146			68			16				8.29						
80		55	2	5.0								185																
81		55	5	1.5							20	170			69			25				8.09						
82		55	5	3.0	62	.0890	.0010	8.91		8.91	18	147			56			31			24.1	7.81		7.70	5.87	3.03	16.1	109
83		55	5	5.0		.0064	.0013				17	200			83			24				8.45						
84		80	5	3.0							35	205			81			25				7.97						
84a	K	55	5	3.0								162																
85	NH_4	30	2	1.5								297										9.04						
86		30	5	1.5							54																	
87		30	5	3.0							54	277																
88		30	5	5.0								336																
89		55	2	5.8								233										8.55						
90		55	5	1.5		.0036	.0007				33	228			105			9				7.94						
91		55	5	3.0	39	.0118	nil	8.90			33	170			77			17			25.3	7.89		8.01	5.52	2.70	16.7	99
92		55	5	5.0				8.80		8.90	33	210	172	101	92	70	42	22	25	22		8.11			5.52	2.15	24.0	56
93		55	5	5.5		.0284	.0023	8.90		8.56		250	215	92	107	76	13	15	20	5		8.32		9.15	5.28	2.19	29.1	47
94		55	5	5.7				8.90		8.74		285			110			3			24.5	8.19		8.29				

Expt No.	Batch number	Temp. °C	Cold-swage time/sec	gill	Composition % weight Cu	Sn	Be	Density g/cm³ as deposited	400° C	1000° C	Shrinkage % (vol × 10³	Hardness Vickers as deposited	400° C	1000° C	Tensile strength lb./in² × 10³ as deposited	400° C	1000° C	Elongation % as deposited	400° C	1000° C	Young's modulus lb./in² × 10⁶ as deposited	Resistivity microhm-cm as deposited	400° C	1000° C	Magnetic properties as deposited Retent.	Br	Bc	μmax
95		90	5	3.0								145			74			24										
96		90	5	3.0		0002	.0014				32	161			67			21							3.40	2.32	29.7	54
97		90	5	3.0		0.026	.0017					167			65			15			29.4				3.40	2.37	29.2	80
98	Sn10Cu3N	20	5	3.0				8.89				232										7.59						
99		20	2	3.0								300																
100		20	5	3.0				8.90				296										8.23						
102		55	5	2.0		0002	.0010															8.24						
103		55	5	4.6		0026	0.0	8.90				176			65			14				8.22						
104		55	2	5.0				8.93				230										8.32			5.74	2.87	20.1	95
105		55	5	5.0		0.001	.0005	8.93			20	160			68			10			19.7							
106		55	5	5.3		0027	.0014															8.01						
107		55	10	5.0				8.91			14	156										8.01						
108		55	20	5.0				8.90				140										8.31						
109		55	20	5.0				8.90				308										8.48						
110		80	5	3.0				8.90				228										8.04						
111		80	10	3.0				8.90				211										7.82						
112		80	20	3.0				8.91				196										8.47						
113		80	5	3.0				8.91																				
114	Sn10Cu4N	20	5	3.0				8.88				376										9.88						
115		20	5	5.0				8.87				328										9.10						
116		55	2	5.0				8.89				295										9.11						
117		55	5	3.0		0028	0.1	8.91				253			82			5				8.19						
118		55	5	5.0		0006	0.02	8.88			28	280			116			2			27.2	8.80						
119		55	10	5.0				8.86				251										8.30						
120		55	20	3.0				8.93				215										7.80						
121		55	20	5.0				8.89				228										8.22						
122		80	5	3.0				8.91				210										8.35						
123		80	10	3.0				8.91				272										8.25						
124		80	20	3.0				8.91				232										8.16						
125		80	20	5.0				8.91				267										8.50						
126	S(C)	20	5	3.0								280										8.29						
127		55	0.5	3.0								252										8.67						
128		55	1	3.0								216										8.50						
129		55	2	3.0								197			84			18				8.17						
130		55	2	5.0											93			3										
131		55	5	1.5		0024	0005				28	201			73			23				7.72			5.58	2.86	28.0	70
132		55	5	3.4	56	0173	0020	8.91		8.91	31	212	138	103	74	64	46	20	30	32	25.1	8.10		8.04	5.60	2.70	23.0	68
133		55	5	5.0		0202	0035	8.91		8.77	14	247			104			5			28.2	8.35		8.25				
134		55	10	3.0							42	208										7.70						
135		55	15	3.0							36	222										7.83						
136		55	25	3.0								206										7.84						
137		55	50	3.0								278										11.14						
138		80	5	3.0								213			83			5				8.00						
139	SpC111	30	5	3.0							41	246										8.14						
140		55	2	3.0								252			103			8				8.54			5.56	2.80	35.4	44
141		55	5	1.5							43	245										8.10						
142		55	5	3.0	51	0244	0016	8.90		8.84	38	248	185	101	92	78	43	11	26	22	26.8	8.21			5.06	2.00	35.4	36.5
143		55	10	3.0							34																	

Expt. No.	Bath	Temp. °C	C.D. amp./in.²	pH	Composition % weight			Density g./cm.³			Stress lb./in.² × 10³	Hardness Vickers			Tensile strength lb./in.² × 10³			Elongation, %			Young's modulus lb./in.² × 10⁶	Resistivity microhm-cm			Magnetic properties as-deposited			
					Co	Cr	Ni	as deposited	400° C.	1000° C.		as deposited	400° C.	1000° C.	as deposited	400° C.	1000° C.	as deposited	400° C.	1000° C.	as deposited	as deposited	400° C.	1000° C.	Bmax.	Hc	Hc	gauss
144		55	15	3.0							40	249			126			7				× 51						
145		55	5	5.0		0044	0956				17	196			91			4				× 54						
146		80	5	3.0		0129	0913				15																	
147	I	30	5	1.5							44	274			58			14				× 59						
148		30	5	3.0							41	230			137			5										
149		30	5	5.0								311																
150		80	5	5.0								242																
151		55	0.5	5.0		0405	0942					215			132			4				50						
154		55	1	5.0								234																
155		55	2	5.0								250										01						
156		55	5	5.0								241										03						
157		55	5	1.5							46	204			92			15			30 ×	× 25			5.22	2.18	34 ×	41
158		55	5	3.0							42	244			102			15			24 ×	× 61						
160		55	5	5.0							55	321			135			6			31							
161		55	5	5.5								310																
162		55	10	5.0								349																
164		55	0.5	3.0								210			58			15				9.47			5.36	2.32	24 ×	31
165		55	25	3.0								212			96			5				7.93						
166		70	5	3.0								202			101			6				7.67						
167		90	5	1.5							11	225			52			12				8.93						
168		90	5	3.0		0028	0889				44	229										7.66						
169		90	5	5.0		0141	0917					209																
170		55	5	3.0								303																
171	α	55	1	3.0		0482	0892				34	334			92			7				10.73						
172		55	5	1.5							32	299										9.82						
173		55	5	3.0		0125	0889				32	302										10.03						
174		55	5	5.0							30	335										9.34						
175		55	10	1.5		0482	0892				42	334			92			7				10.73						
176	CrA	55	5	3.0		0730	0911				34	299										9.82						
177		55	5	5.0		0564	0952					302										10.03						
178		55	10	3.0		0727	0134					335										9.34						
179		55	10	5.0								261										9.99						
180		30	2	3.0								342										11.16						
181	Cr	30	5	3.0								317																
182		55	5	3.0								241										8.40						
183		55	5	2.0								276										9.25						
185	A	30	5	4.5							35	212			58			4			22 ×	9.10						
186		30	5	4.5								255										9.34						
187		30	5	4.5		0102	0916					335			147			4				9.15			5.09	2.75	61.5	31
188		30	10	4.5								369										8.32						
189		55	5	4.5							37	342			161			4				8.95						
190		55	5	3.0								342										9.45						
191	A	30	5	3.0								252										9.44						
192		55	5	3.0								283																
193		55	5	2.0							30																	

Expt. No.	Bath Number	Temp. °F.	C.D. amp./dm²*	pH	Composition, % weight			Density, g./cm³			Stress lb./sq. in. × 10³	Hardness Vickers				Tensile strength lb./sq. in. × 10³				Elongation, %				Young's modulus lb./sq. in. × 10⁶	Resistivity microhm-cm.			Magnetic properties as-deposited			
					Ni	Co	Fe	as deposited	400° C.	1000° C.		as deposited	400° C.	1000° C.		as deposited	400° C.	1000° C.		as deposited	400° C.	1000° C.		as deposited	400° C.	1000° C.	Hmax	Br	Hc	μmax
194		55	5	2.5				× 81				188																		
195		55	5	3.0		1407	0406	× 81	× 81	× 86	1	174				92				30				25.4	× 18	× 29	× 37				
196		55	5	3.5	28							172													7.36		7.44				
197		55	5	4.5	14	1081	0012	× 02				150				60				22					× 02		× 14	3.50	3.06	29.0	24
198		55	10	3.0								211													7.93						
199	Am.	25	2	3.5				× 81				482													28.30						
200		25	5	3.5		2000	0222	× 83				525													33.30						
201		55	2	3.5		0013	0041	× 02				481				90									× 70		14.90				
202		55	5	3.5								556																			
203		55	7	3.5		0710	0221	× 77			44	550													11.21						
204		55	10	3.5								566													12.22						
205		80	5	3.5		1810	0007	× 82				491				170				1					9.08						
206		80	10	3.5				× 82				525													9.56						
207		80	5	3.5							0					165				1											
208	*		3		82	1100	0114	× 82		7.18		568				225	27			4	1				12.43		11.12	4.90	2.52	55.0	31
209			4					× 66		7.42		617	505	39											14.80		9.85				
210			5		81	0153	0037	× 87								222	12	7		1	1			24.7	11.00			5.33	1.63	20.5	33
211	½		3			0140	0.093									140				5											
212			4					× 90		× 27		567	350	93											9.36		× 89	4.70	2.80	70.5	27
213			6		55	0139	0014					583				193				5				23.8	8.27			4.72	2.76	68.0	27
214	*		2		97	0075	0009	× 92								196				5				22.8							
215			3					× 88		7.76		572	383	63											13.03		10.05				
216			4		1.10	0065	0014	× 92								220				6								4.77	2.25	80.5	28
217	‡		4.5					× 62		× 28		823	605	58											18.93		10.22				
218			5		58	0155	0021	× 88				619				227				1				24.4				5.16	1.15	25.4	34.5
219	*		1.7		86	0113	0029	× 91								232	6	8	8	3		1						5.28	2.12	36.5	18
220			4		70	0175	0051	× 89				617				191			10	1											
221								× 83	× 83	× 82		586	398	70											11.27	× 77	× 32				
222	‡	65	5	2.3		0014	0006	× 90				599				78				9					× 81			5.29	2.27	38.4	33
223	‡	65	10	2.3								173													10.47						
224		55	5	3.7																					11.34						
225		65	2	3.7								408																			
226		65	5	3.7	1.08	0141	0023	× 90		× 62	15	569	202	95		206	83	40		4	25	23		25.8	11.40		× 78	4.61	2.45	71.5	25
227		65	10	3.7								[illegible]515													[illegible]8.93						
228		65	15	3.7								291													8.52						
229		65	20	3.7								287													8.56						
230		65	25	3.7								251													8.38						
231	OB	55	5	2.5	66	0085	0011	× 82	× 84	× 82	4	483				210				5					10.12	× 65	× 94	5.33	2.90	52.6	39
232	OT	55	5	2.5				× 80				415													8.58		× 41				
233	OBT	55	5	2.5				× 80				544													10.70		× 38				
234		55	2	3.5	88	0072	61	× 88	× 86	× 85		442				170	29	25		2	1	5			9.17	× 38	× 55				
235		55	5	3.5	57	0050	0010	× 80	× 86	× 85	6	496	218	82		212	35	23		5	0	4			10.03	× 30	× 42	4.98	2.33	52.5	28.5
236		55	10	3.5				× 87	× 89	× 85	5	518				233				3					10.63	× 27	× 31				

*Amp./dm² × 0.29 = amp./in².
†Deposits exfoliated.
‡Semi-bright.

TABLE II. COMPOSITION OF NICKEL PLATING SOLUTIONS

No.	Bath Symbol	Bath Type	Nickel sulfate ($NiSO_4 \cdot 7H_2O$)			Nickel chloride ($NiCl_2 \cdot 6H_2O$)			Boric acid (H_3BO_3)			Other Constituents				
			N	g/l	oz/gal	N	g/l	oz/gal	N	g/l	oz/gal	Substance	Formula	N	g/l	oz/gal
1	S	All sulfate	2.0	280	38				0.5	30	4					
2	oS	All sulfate cobalt free	2.0	280	38				0.5	30	4					
3	$S_{III}C_I$	Watts type	1.5	210	28	0.5	60	8	0.5	30	4					
4	$oS_{III}C_I$	Watts type cobalt free	1.5	210	28	0.5	60	8	0.5	30	4					
5	Na	Watts and sodium sulfate	1.5	210	28	0.5	60	8	0.5	30	4	Sodium sulfate	Na_2SO_4	0.5	36	5
6	K	Watts and potassium sulfate	1.5	210	28	0.5	60	8	0.5	30	4	Potassium sulfate	K_2SO_4	0.5	44	6
7	NH_4	Watts and ammonium sulfate	1.5	210	28	0.5	60	8	0.5	30	4	Ammonium sulfate	$(NH_4)_2SO_4$	0.5	33	4.5
8	$S_{III}C_I$-1N	Watts type	0.75	105	14	0.25	30	4	0.5	30	4					
9	$S_{III}C_I$-4N	Watts type	3.0	420	57	1.0	120	16	0.5	30	4					
10	S_IC_I	Sulfate chloride	1.0	140	19	1.0	120	16	0.5	30	4					
11	S_IC_{III}	Sulfate chloride	0.5	70	9.5	1.5	180	24	0.5	30	4					
12	C	All chloride				2.0	240	32	0.5	30	4					
13	oC	All chloride cobalt free				2.0	240	32	0.5	30	4					
14	C-4N	All chloride				4.0	480	64	0.5	30	4					
15	Cx	All chloride very acid				2.0	240	32				Hydrochloric acid (concentrated)	HCl	1.5	120 ml/l	
16	Ac	Chloride acetate				1.1	130	17				Nickel acetate	$Ni(C_2H_3O_2)_2 \cdot 4H_2O$	1.1	135	18
17	F	Fluoborate							0.5	30	4	Nickel fluoborate	$Ni(BF_4)_2$	2.0	232	31
18	Am	Ammoniacal nickel	1.5	210	28	0.5	60	8				Ammonium hydroxide	NH_4OH	Excess		
												Ammonium sulfate	$(NH_4)_2SO_4$	0.75	50	6.5
19	f	Cobalt bright nickel	1.7	240	32	0.25	30	4	0.5	30	4	Nickel formate	$Ni(HCO_2)_2$	0.6	45	6
												Cobalt sulfate	$CoSO_4 \cdot 7H_2O$	0.02	2.6	0.35
												Ammonium sulfate	$(NH_4)_2SO_4$	0.01	0.75	0.1
												Formaldehyde	CH_2O		2.5	0.33
20	OBT	Organic bright nickel	1.5	210	28	0.5	61	8	0.5	30	4	Nickel benzene-disulfonate			7.5	1.0
												Triaminotolyldiphenyl-methane chloride (reduced Fuchsin)			5-10 mg/l	

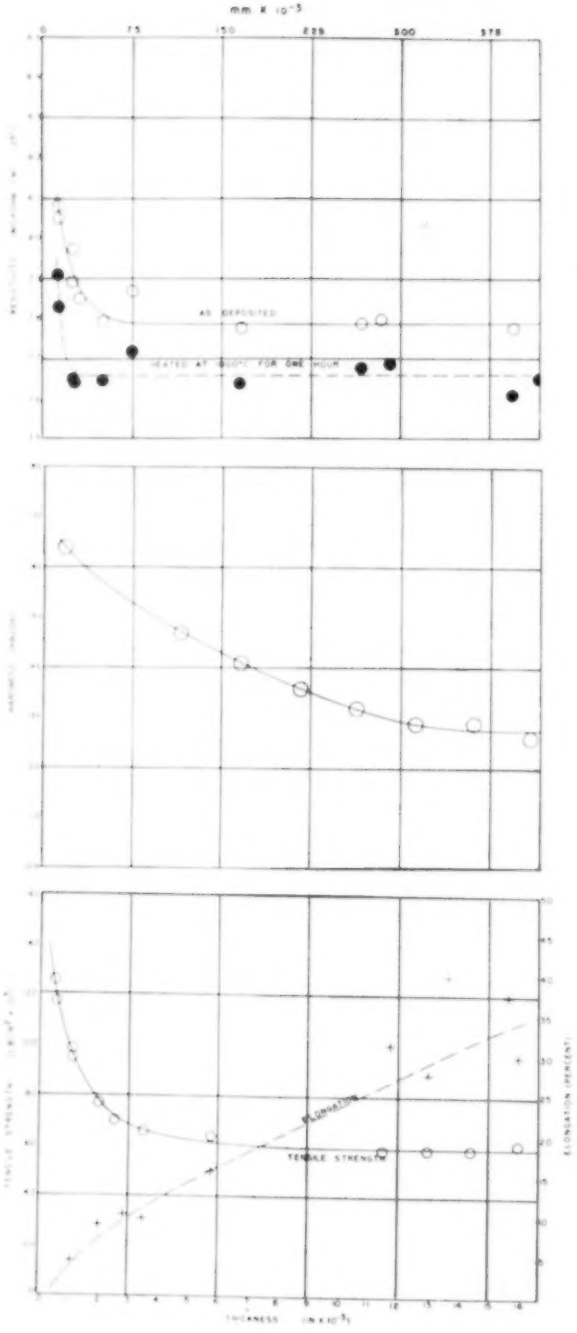


Fig. 1. Variation of hardness, tensile strength, and electrical resistivity with thickness of nickel coatings deposited from the $NiCl_2$ bath at 55° C (131° F), 5 amp dm² (46 amp ft²), and pH of 3.0

ble, the consistent production of deposits with certain desired properties is difficult to attain.

This project was set up under the auspices of the American Electroplaters' Society at the National Bureau of Standards. The paper represents a cooperative research effort of various Divisions and Sections of the Bureau which assisted in measuring and collecting the data on physical and mechanical properties of nickel electrodeposits. Their help will be acknowledged in the appropriate sections of this paper.

This study involved measurements or determinations of the following: cathode current efficiencies and internal stress of the deposits during deposition; chemical composition of deposits; structure by optical microscopy, electron-microscopy and X-ray diffraction; mechanical properties (hardness, tensile strength, elongation, yield strength, Young's modulus of elasticity, fatigue limit and internal friction); density and thermal properties (thermal expansion, specific heat and heat of solution); electrical resistivity and magnetic properties. The effects of heat treatment on many of these properties were studied.

Table I summarizes the values of the more important properties for each deposit produced in this study and includes the conditions of deposition and in most cases the composition of the deposit. The symbols in column 2 refer to the bath compositions given in Table II.

A literature survey containing 152 references was published previously[15] and two annual progress reports on this project have appeared in print[17,18]. At the end of this paper a complete list of references, including the one already published, has been compiled in the form of a bibliography.

II. PREPARATION OF PLATING SOLUTIONS AND DEPOSITS

Solutions

All solutions with the exception of the cobalt-free solutions were prepared from a good commercial grade of salts. The cobalt-free nickel sulfate solutions were prepared from C.P. cobalt-free nickel sulfate[a,g]. The cobalt-free nickel chloride was prepared by dissolving cobalt-free Mond nickel shot in pure hydrochloric acid and evaporating the solution to dryness[b].

A standard procedure was followed in removing harmful impurities. An excess of hydrogen peroxide[c] was added to each solution and after the temperature was raised to 60° C (140° F) the *p*H was increased to about 5.8 by adding a slurry of nickel hydroxide[d] or carbonate[e]. In some instances barium hydroxide[f] was added to a sulfate solution. Activated carbon[g] was then stirred into the solution

[a, b, c, d, e, f, g, h, i, j, see Appendix.

together with some siliceous filter aid. After standing for a few hours the solution was filtered. It was then electrolyzed with a corrugated cathode at low average current densities, 0.2 to 0.5 amp/dm² (2 to 5 amp/ft²), for a number of days, and finally at 10 amp/dm² (93 amp/ft²) for a few hours. Prior to the plating of test specimens a dummy cathode was used until a satisfactory deposit was obtained. The empirical rule of the practical electroplater that a nickel bath has to be worked or aged for some time before yielding satisfactory deposits is fully supported by observations made in the course of this study. It was found that the only safe way of purifying a new or a contaminated bath was by thorough dummying. It was observed several times that about 30 ampere-hours per liter (114 ampere-hours per gallon) are necessary to bring a new bath to a stable equilibrium condition; only from a bath thus purified can deposits with reproducible physical properties[5] and identical microstructures be obtained. Such an extreme purification may not be necessary in practical electroplating.

Table II gives the composition of all plating solutions used in this investigation together with the designating symbols. The composition of a bath is indicated by symbols that designate the main constituents or variables, for example, "S" for sulfate and "C" for chloride. The ratio of sulfate to chloride in the bath is indicated by Roman numeral subscripts, for example, $S_{III}C_I$ indicates a bath containing three-fourths of the nickel as sulfate and one-fourth of the nickel as chloride. The symbols used to recall the important variables in the composition of the bath have the following meanings:

S = Sulfate
C = Chloride
Ac = Acetate
Na = Sodium sulfate
K = Potassium sulfate
NH_4 = Ammonium sulfate
o before a symbol = cobalt-free bath

Where the content of nickel was not 2 *N*, the bath symbol is followed by a mark such as 1 *N* or 4 *N* to indicate the concentration of the nickel.

The concentration of nickel in most of the plating solutions was 2 *N* or about 60 g/l (8 oz/gal), except for a few baths in which the concentration was 1 *N* or 4 *N*. The concentration of boric acid in all solutions in which it was present was 0.5 M or 30 g/l (4 oz/gal). The plating solutions were prepared with distilled water and were analyzed periodically for the major constituents, the concentrations of which were maintained within ±2 per cent.

Each bath had a volume of 10 to 15 liters (2.5 to 4 gal), and was contained in a rectangular glass battery jar. The plating solutions were heated either externally by a water bath or internally by quartz-jacketed immersion heaters. The temperature was controlled thermostatically to ±1° C. The solutions were stirred by motor-driven glass stirrers at a rate sufficient to maintain a constant temperature throughout the solution. In a few cases, filtered air was used for agitation. The current density was controlled to within ±5 per cent. Since the solutions were stirred, the range of current densities permissible without burning the deposit was somewhat higher than in a still bath.

The *p*H of the solution was measured at intervals with a commercial glass-electrode *p*H meter, and usually was controlled by letting dilute acid drip into the solution. This acid consisted of sulfuric acid or a mixture of sulfuric and hydrochloric acids mixed in the same ratio as the sulfate-chloride ratio in the baths. The *p*H of a solution was raised when necessary either by adding nickel hydroxide or nickel carbonate or by operating the solution with large anodes and a very small cathode area (a wire or a small tube) at very high cathode current densities. The latter procedure was found to be more convenient and much less time-consuming since, under these conditions, the anode efficiency is much greater than the cathode efficiency and the *p*H of the solution can be increased in a short time. Additions of hydrogen peroxide helped to increase the *p*H when the bath was electrolyzed at high cathode current densities.

The anodes consisted of electrolytic nickel sheets containing 99.4 per cent nickel (balance cobalt and trace elements)[5] which were bagged with double layers of glass cloth that had been degreased and heated to 450° C for one hour. Cobalt-free anodes were used in the cobalt-free solutions[5] and special anodes that contained 1 per cent of cobalt were used in the bright cobalt-nickel bath designated f in Table II.

Pitting, the persistent trouble maker, was eliminated or reduced to a minimum by occasional additions of hydrogen peroxide, usually about 0.5 ml of the 30 per cent solution per liter, together with frequent filtration and operation at low current densities and elevated temperatures. The solution was tested with potassium permanganate to establish the complete decomposition of hydrogen peroxide before any test specimens were plated.

Deposits

Test specimens were produced by depositing nickel in sheet or tubular form. The starting sheets and tubes were cleaned before plating by degreasing with an organic solvent, scrubbing with powdered magnesium oxide, and dipping in dilute hydrochloric acid. Care was taken to obtain a surface free from "water-break". The sheet specimens were made by plating nickel upon both sides of polished

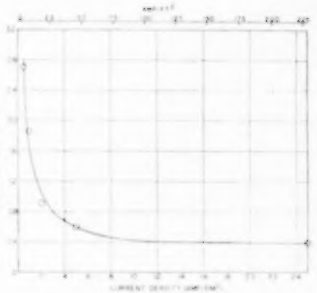


Fig. 2. Effect of current density on cobalt content of nickel deposited from the $S_{III}C_I$ bath at 55° C (131° F), and pH of 4.0

stainless steel or Inconel panels, each 15 x 38 cm (6 x 15 inches), which were placed midway between two anodes of similar size. The sheet nearly filled the cross section of the vessel, an arrangement which afforded a fairly uniform current density over the sheet. To separate the nickel, the edges of the plated sheet were sheared off. In most cases there was little or no adhesion to the starting sheet.

Tubular specimens were prepared by depositing nickel on smooth, buffed copper tubes 0.5 cm (3/16 inch) in diameter and 28 cm (11 inches) long. Subsequently the copper base was dissolved out in a solution containing 500 g of chromic acid and 50 g of sulfuric acid per liter. Specimens for measurements were cut from the best portions of the sheet or tube and were usually from 0.18 to 0.30 mm (0.007 to 0.012 inch) thick. The following ranges of plating conditions were used[5] in preparing test specimens. The *p*H was varied over a range of 1.0 to 5.8, the temperature from 10° to 80° C (50° to 176° F), and the current density from 0.25 to 50 amp/dm² (2.3 to 470 amp/ft²).

In addition to the deposits made from solutions with the compositions stated in Table II, deposits on similar cathodes

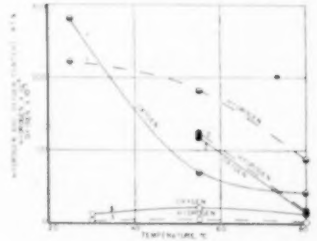


Fig. 3. Effect of temperature of plating bath on oxygen and hydrogen content of nickel deposited at 5 amp/dm² (46 amp/ft²). Curve 1. Bath Am, pH 8.5; Curve 2. Bath C, pH 5.0; Curve 3. Bath $S_{III}C_I$, pH 4.5 to 5.0

TABLE III. PHYSICAL AND MECHANICAL PROPERTIES OF COBALT-CONTAINING AND COBALT-FREE NICKEL DEPOSITS

Plating Conditions			Cobalt* content	Resistivity microhm-cm		Resistivity difference	Hardness Vickers		Tensile strength lb/in² × 10³		Elongation %		Internal Stress lb/in² × 10³	
Temp. C	C.D. amp/dm²	pH	%	$S_{III}C_I$	$oS_{III}C_I$		$S_{III}C_I$	$oS_{III}C_I$	$S_{III}C_I$	$oS_{III}C_I$	$S_{III}C_I$	$oS_{III}C_I$	$S_{III}C_I$	$oS_{III}C_I$
30	2	3	1.37	8.23	7.66	0.57	174	205						
30	5	3	0.37	7.83	7.66	0.17	182	165	75	73	15	13	35	40
55	0.5	3	1.90	9.42	7.59	1.83	203	178						
55	1	3	1.87	8.68	7.43	1.25	200	194						
55	2	3	1.07	8.13	7.49	0.64	139	138	56	53	23	30		
55	5	1.5	0.66	7.86	7.50	0.36			67	62	28	31	24	28
55	5	3	0.54	7.76	7.44	0.32	150	142	56	60	28	31	17	15
55	5	5	0.89	7.94	7.41	0.53	160	192	59	73	25	23	25	23
55	10	3	0.65	7.78	7.41	0.37	161	186						
55	25	3	0.35	7.88	7.76	0.12	195	234						
80	5	3	0.60	7.87	7.55	0.32	182	188	78	79	28	25		
				C	oC		C	oC	C	oC	C	oC	C	
55	5	1.5	1.14	8.26	7.65	0.61	204	210					46	37
55	5	3	0.96	8.24	7.71	0.53	244	228	102	97	14	17	42	37
55	5	5	1.79	8.93	7.85	1.08	321	299					55	51
				S	oS		S	oS	S	oS	S	oS	S	
55	5	1.5	1.31	8.71	7.44	1.27	215	182	82	83	20	14		

*Cobalt content of $S_{III}C_I$, C, and S deposits. $oS_{III}C_I$, oC, and oS are cobalt-free.

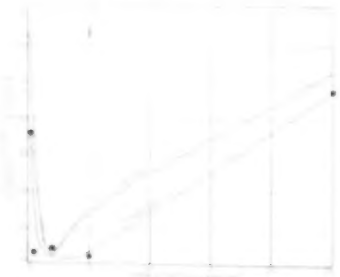


Fig. 4. Effect of current density on oxygen and hydrogen content of nickel, deposited from $S_{III}C_I$ bath at 55° C (131° F), and pH of 3.0

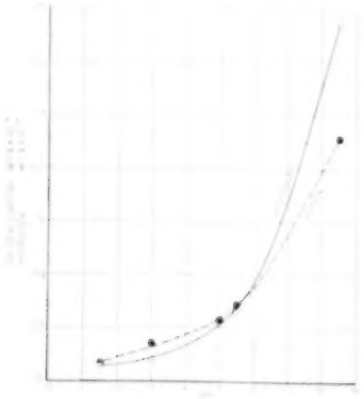


Fig. 5. Effect of pH of plating bath on oxygen and hydrogen content of nickel deposits. Average values for 26 deposits obtained from 10 different solutions at various temperatures and current densities

from the proprietary bright nickel baths now in commercial use were obtained from various firms. Those baths and deposits are designated in this report as a, b, c, d, and e without disclosure of their identity or bath composition. In most cases three current densities, as reported in Table I, were used for deposits from each of the proprietary baths. The corresponding data indicate whether the physical properties here reported vary greatly with such differences in current density as may be expected on articles with irregular shapes.

Effect of thickness of deposit on physical properties

The physical properties of a deposit may vary appreciably with thickness, hence it is important to know whether a thickness exists beyond which the properties became sensibly constant. The variations in properties with thickness are especially significant for deposits from the sulfate-chloride bath of the Watts type. Fig. 1 shows the variation of hardness, tensile strength, elongation, and electrical resistivity with thickness. The effect is most pronounced with the thin deposits. A set of specimens 0.013, 0.025, and 0.175 mm (0.0005, 0.001, and 0.007 inch) in thickness was heated to 1000° C (1832° F) in vacuo for one hour. Their tensile strengths then showed no variation with thickness, indicating that the differences

in the metal as deposited were caused by differences in the structure of the deposits and not by the thickness as such. These variations in tensile strength, elongation, hardness, and resistivity are correlated with the grain size of the deposit and will be discussed later in connection with the photomicrographs of the structure (Section IV). In general, the grain size of a deposit from a Watts-type bath increases with thickness. In contrast, the grain size of a deposit from the C (all chloride) bath does not vary with the thickness and its photomicrograph shows a homogeneous structure with no apparent variation in grain size with thickness. Consequently, the physical properties of these deposits should vary with thickness less than do deposits from the Watts bath.

To minimize thickness as a variable, tests were made on deposits with a thickness of at least 0.18 mm (0.007 inch). Most test specimens were over 0.25 mm (0.01 inch) thick.

III. COMPOSITION OF DEPOSITS

Electrodeposited metals usually contain metallic and nonmetallic impurities in amounts which depend on the purity of the bath, the bath composition, the anode composition, and the conditions of deposition. By the methods of careful purification outlined in Section II practically all metallic impurities, with the exception of cobalt, were removed from the experimental solutions.

A. Cobalt Content

All nickel deposits produced from solutions made from commercial nickel salts and operated with cast, rolled, or electrolytic anodes manufactured in the U.S.A. contain a certain amount of cobalt. The electrolytic nickel used as anodes in the baths contained an average of 0.6 per cent cobalt. The commercial nickel sulfate and nickel acetate used to prepare the baths each contained 0.4 per cent, and the nickel chloride 1.0 per cent of cobalt, based on the metal content of the salt.

The cobalt content of a nickel deposit depends on the composition of the plating solution and also on the current density. The data on the cobalt content of the deposits can be correlated only approximately with the conditions of deposition, since it was not feasible to keep the cobalt content of a given solution constant. The cobalt content of the deposits was determined by a spectrophotometric method, with thiocyanate and acetone as color-forming agents. The precision of this method was about 10 per cent of the cobalt content. Some of the results were checked by a polarographic method[18]. Another method which was quite satisfactory involved the potentiometric titration of cobalt in a strongly ammoniacal solution with potassium ferricyanide[19].

TABLE IV. OXYGEN AND HYDROGEN CONTENTS OF NICKEL DEPOSITS

No.	Bath	Temp. °C	C.D. amp dm²	pH	Oxygen % weight	Hydrogen % weight	Ratio O:H
1	S	30	5	1.5	0.0016	0.0002	8*
2		55	5	1.5	0.0140	0.0011	13
3		55	5	3.0	0.0304	0.0010	30*
4		55	5	5.0	0.0173	0.0017	10
5	oS	55	5	1.5	0.0139	0.0011	13
6	$S_{III}C_I$	10	2	3.0	0.0101	0.0067	2
7		30	2	5.0	0.0123	nil	
8		30	5	1.5	0.0063	0.0007	9*
9		30	5	3.0	0.0092	nil	
10		30	5	5.0	0.0207	0.0006	34*
11		55	0.25	3.0	0.0627	0.0038	16
12		55	0.50	3.0	0.0315	0.0003	110*
13		55	2	3.0	0.0020	nil	
14		55	2	5.5	0.0142	0.0017	8
15		55	5	1.5	0.0070	0.0005	14*
16		55	5	3.0	0.0230	0.0002	115*
17		55	5	5.0	0.0340	0.0008	43*
18		55	5	5.5	0.0427	0.0074	6
19		55	5	5.6	0.0650	0.0016	40*
20		55	25	3.0	0.0527	0.0048	11
21		80	5	3.0	0.0082	0.0004	20*
22		80	5	4.0	0.0099	nil	*
23		80	10	4.0	0.0180	nil	*
24	$oS_{III}C_I$	30	2	3.0	0.0086	0.0010	8
25		55	5	3.0	0.0110	0.0001	110*
26		55	5	5.0	0.0368	0.0036	10
27	Na	30	5	3.0	0.0024	0.0005	5*
28		55	2	3.0	0.0042	0.0008	5*
29		55	5	3.0	0.0090	0.0010	9
30		55	5	5.0	0.0064	0.0013	5
31	NH_4	55	5	1.5	0.0036	0.0007	5*
32		55	5	3.0	0.0118	nil	
33		55	5	5.5	0.0284	0.0023	12
34		80	5	3.0	0.0062	0.0014	4
35		80	5	5.0	0.0156	0.0017	9
36	$S_{III}C_I$-1N	55	5	2.0	0.0085	0.0003	28*
37		55	5	3.0	0.0076	nil	
38		55	5	5.0	0.0101	0.0009	11*
39		55	5	5.3	0.0077	0.0004	19*
40	$S_{III}C_I$-4N	55	5	3.0	0.0028	nil	
41		55	5	5.0	0.0689	0.0107	6
42	S_IC_I	55	5	1.5	0.0024	0.0005	5*
43		55	5	3.0	0.0173	0.0020	8
44		55	5	5.0	0.0262	0.0035	8
45	S_IC_{III}	55	5	3.0	0.0244	0.0016	15
46		55	5	5.0	0.0344	0.0050	7
47		80	5	3.0	0.0129	0.0013	10
48	C	55	1	5.0	0.0408	0.0042	10
49		55	5	1.5	0.0150	0.0010	15
50		55	5	3.0	0.0107	0.0005	21*
51		55	5	5.0	0.1170	0.0124	9
52		80	5	3.0	0.0028	0.0009	3*
53		80	5	5.0	0.0140	0.0017	8

TABLE IV. OXYGEN AND HYDROGEN CONTENTS OF NICKEL DEPOSITS (*Continued*)

No.	Bath	Temp. °C	C.D. amp/dm²	*p*H	Oxygen % weight	Hydrogen % weight	Ratio O/H
54	sC	55	5	3.0	0.0125	0.0009	14*
55	C4N	55	5	3.0	0.0462	0.0097	5
56		55	5	5.0	0.0730	0.0101	7
57		55	10	3.0	0.0504	0.0057	9
58		55	10	5.0	0.0727	0.0134	6
59	Cx	55	5		0.0393	0.0046	8
60	Ac	50	5	4.5	0.0162	0.0016	10
61	F	55	5	3.0	0.0097	0.0009	10*
62		55	5	4.5	0.0091	0.0012	8
63	Am	25	5	8.5	0.2809	0.0222	13
64		55	2	8.5	0.0643	0.0141	4
65		55	7	8.5	0.0770	0.0223	3
66		30	5	8.5	0.0419	0.0087	5
67	a		3		0.0100	0.0014	7
68			6		0.0153	0.0037	4
69	b		3		0.0049	0.0009	5*
70			6		0.0139	0.0014	10
71	c		2		0.0073	0.0009	8*
72			4		0.0095	0.0014	7
73	d		4		0.0155	0.0021	7
74	e		1.7		0.0113	0.0029	4
75			4		0.0175	0.0051	3
76	f	65	5	2.3	0.0014	0.0006	2*
77		65	5	3.7	0.0141	0.0023	6
78	OB	55	5	2.5	0.0080	0.0011	7
79	OBT	55	2	3.5	0.0072	nil	
80		55	5	3.5	0.0050	0.0010	5
							Av. 8 ±2.6

*Indicates values not included in the average.

Fig. 6. Deposit with two different structures obtained at extreme conditions of temperature and current density. Cross section x 250. $S_{II}C_I$ bath at 80° C (176° F), 10 amp/dm² (93 amp/ft²), and pH of 5.0

Coarse-grained structure (upper part) has a Vickers hardness of 159; a fine-grained structure (lower part) has a Vickers hardness of 227

The cobalt determinations with the polarograph were done by J. K. Taylor and R. E. Smith of this Bureau; the colorimetric or potentiometric analyses by F. Ogburn and K. E. Christoph. Variations in the temperature, *p*H, and composition of the plating bath produced only minor changes in the cobalt content of nickel deposits, but the current density had a large effect. Fig. 2 illustrates the effect of current density on the cobalt content of nickel deposits prepared in a $S_{II}C_I$ bath, containing about 0.36 g of cobalt per liter, at 55° C (131° F) and a *p*H of 3. The deposits obtained at low current densities contained much more cobalt than those plated at high current densities. The same effect of current density has been observed by Weisberg[105] in his study of the bright cobalt-nickel bath. In Table III various physical and mechanical properties of nickel deposited from the ordinary cobalt containing bath are compared with similar deposits from cobalt-free solutions. With the exception of the resistivity, the effects of small amounts of cobalt on the properties of the deposits seem to be within the limits of the reproducibility of the deposits. The resistivities of cobalt-free deposits are appreciably lower than those of ordinary cobalt-containing ones. This result is in accord with the well-known effect of impurities in increasing resistivity. The data show that the resistivity is a sensitive measure of the purity of a deposit. The effect of cobalt on resistivity and on other properties of commercial nickel is mentioned in the literature[18] (p. 32). The relation between the resistivity and the cobalt content of nickel deposits is treated in detail in Section VIII of this paper.

As the content and distribution of nonmetallic impurities in nickel deposits may have considerable effects on their physical properties, the percentages of hydrogen, oxygen, chloride, carbon, and sulfur in the deposits were determined. No observations were made on the distribution of impurities.

B. Hydrogen and Oxygen Content

General

Electrodeposited nickel usually contains measurable amounts of hydrogen and oxygen. The literature contains no mention of quantitative measurements of the relation between the oxygen contents of nickel deposits and the conditions of deposition and bath composition, although the presence of oxygen, ascribed to the codeposition of basic compounds, has been reported[26,42,57]. On the other hand, in the literature numerous references exist concerning the occurrence of hydrogen in nickel deposits, the influence of conditions of deposition on the hydrogen content, and the relation of hydrogen content to the structure and physical prop-

erties, especially internal stress and hardness. Quantitative data on the hydrogen contents of electrolytic nickel are contained in the following references:[12,19,127,131,146]

Several theories have been proposed to explain the presence of hydrogen in the electrodeposited metals of the iron group. These metals may dissolve the hydrogen in the atomic state, which may enter the crystal lattice to form an interstitial compound or may be absorbed in rifts and discontinuities[18,58,66,78,91,117,124,167,169,175]. In addition hydrogen may be introduced through the inclusion of basic nickel salts, nickel hydroxide, or hydrated nickel oxide, which may be present in the cathode film as colloidal material. The oxygen content of nickel deposits originates almost certainly from this source[12,21].

The contents of hydrogen and oxygen in nickel deposits vary widely with the conditions of deposition and the bath composition, but their concentrations are small compared with those found in electrolytic chromium[182]. The oxygen content of most nickel deposits ranges from a few thousandths to a few hundredths of a per cent and rarely reaches a tenth of a per cent. The hydrogen content is usually not more than a few thousandths of a per cent.

Oxygen and hydrogen were determined by the vacuum fusion method which involved introducing a 0.5 g sample of nickel into outgased molten iron at 1600° C (2912° F) contained in a graphite crucible and hence saturated with carbon. The apparatus was highly evacuated, and the hydrogen was given off uncombined while the oxygen was evolved as carbon monoxide[18,202]. The determinations were made by noting the decrease in pressure of the system as the gases were consecutively removed by oxidation and absorption. This method has the important advantage that the determination of both constituents can be made on a single sample. The measurements were made by J. T. Sterling of the Metallurgy Division of this Bureau.

In interpreting the analyses several factors must be considered. The contents of oxygen and hydrogen are small; the analytical difficulties involved in determining small amounts of oxygen in electrolytic nickel are well known and have been mentioned by Hothersall and O'Sullivan[12,131] (p. 1230). A rough parallelism exists between the oxygen and hydrogen contents of nickel deposits, as shown in Table IV. If all the oxygen to hydrogen weight ratios in Table IV are averaged, the result is about 15. However, if the experiments in which the percentage of hydrogen was below 0.001 per cent are discarded because of their doubtful accuracy, and, if in addition the two excessively high ratios of 40 and 30 are discarded, the remaining 46 experiments give an average value for the ratio of

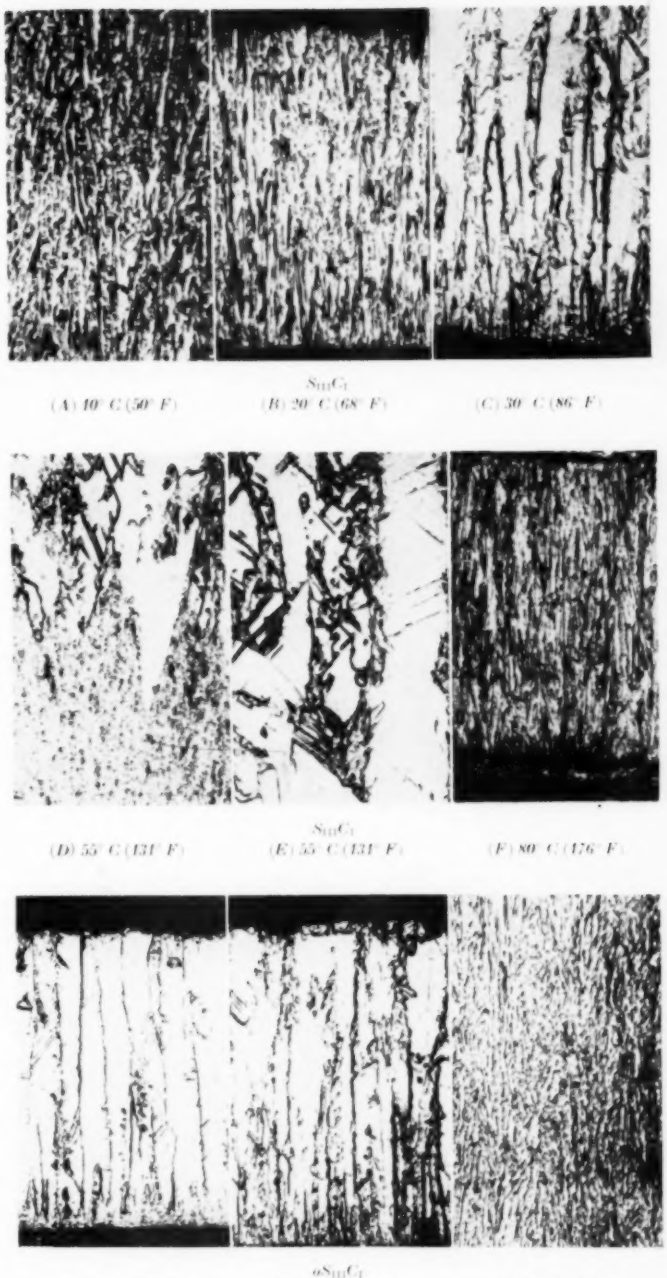
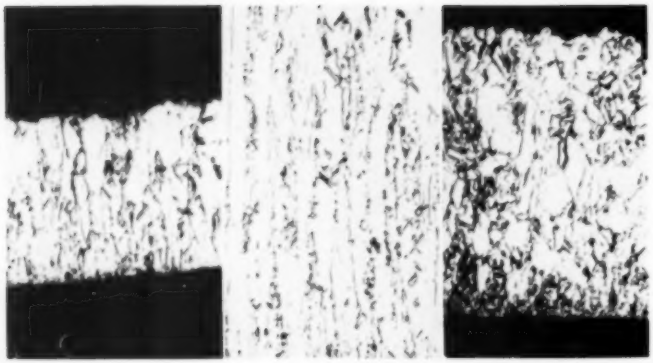
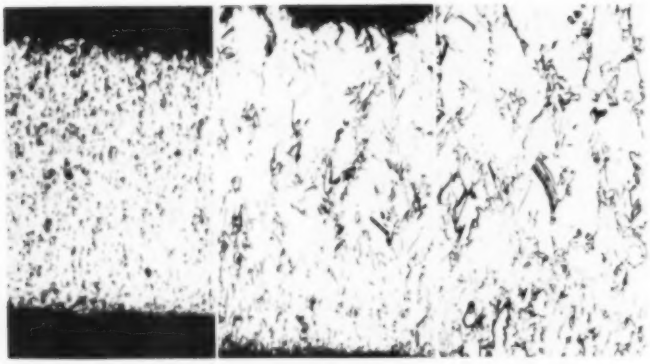


Fig. 7. The effect of temperature of the plating bath on the structure of nickel deposited at 5 amp dm² (56 amp ft⁻²), and a pH of 3.0. Cross section x 250. Etchant: glacial acetic and nitric acid



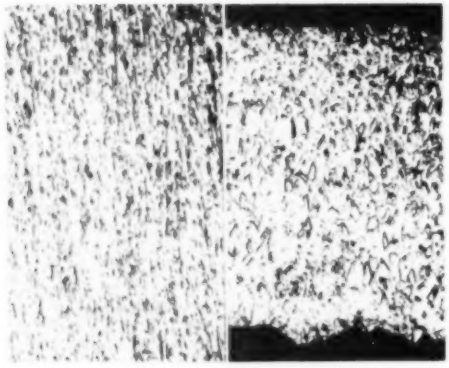
$S_{III}C_1$ at pH 5.0

(A) 30° C (86° F) (B) 55° C (131° F) (C) 80° C (176° F)



$S_{III}C_1$ at pH 1.5

(D) 30° C (86° F) (E) 55° C (131° F) (F) 80° C (176° F)



C at pH 3.0

(G) 30° C (86° F) (H) 80° C (176° F)

Fig. 7a. Effect of temperature of the plating bath on the structure of nickel deposited at 5 amp/dm² (26 amp/ft²). Cross section x 250. Etchant: glacial acetic and nitric acid

3.0 ± 2.6. This is approximately equal to the ratio of 3 ± 2.9 which was found for chromium[52]. It is interesting that the ratios should be so similar for deposits obtained from entirely different types of bath. This result indicates a similarity in the mechanism and nature of the inclusions. A ratio of 3 indicates that oxygen and hydrogen are present approximately in the proportions in which they exist in water. This might be explained on the assumption that the inclusions are hydrous oxides of the type $MO_x \cdot n\,H_2O$, in which n is much larger than x. Another possibility is that the oxygen and part of the hydrogen exist in the inclusion in the form of hydroxyl groups (in which the oxygen to hydrogen ratio is 16) and that sufficient free hydrogen is present in the deposit to reduce the ratio to about 3. The presence of significant amounts of free water in the deposits is unlikely since none can be removed by moderate heating. High temperatures are required to drive out the hydrogen and even then most of the oxygen is always left behind in the deposit.

In the following paragraphs the effects of the conditions of deposition on the content of oxygen and hydrogen in nickel deposits will be discussed. The relation between the content of hydrogen and oxygen and the physical and mechanical properties of deposits will be taken up in later chapters. In general there is no such clear-cut relation as was found with chromium deposits.

1. *Relation of Oxygen and Hydrogen Content to Operating Conditions*

Bath temperature

In the electrodeposition of chromium from chromic acid plating solutions a very marked decrease in the content of hydrogen and oxygen in the deposit occurred with increasing temperature of the bath[52]. Similar data on the hydrogen and oxygen contents of nickel deposited at various temperatures are not so conclusive. The deposit from the ammoniacal (Am) solution (curves 1, Fig. 3) showed a very marked decrease in hydrogen and oxygen content as the temperature increased from 30° C to 80° C and deposits obtained from chloride bath at 80° C contained less oxygen than the deposits obtained at 55° C (curves 2). The data on the deposits from the $S_{III}C_1$ solutions indicate that the differences in oxygen and hydrogen content are within the experimental error (curves 3).

The variations in the hydrogen contents of the deposits from the $S_{III}C_1$ and the C baths (curves 2 and 3, Fig. 3) paralleled the variations in the oxygen contents.

The most plausible explanations for the decrease in oxide content of the deposits with increase of temperature of deposition are (1) that the increased fluidity of the

solution and the higher rate of diffusion of the ions keeps the *p*H of the cathode film at a lower value (this hypothesis would not explain the difference between the $S_{III}C_l$ and the C bath shown in Fig. 3), and (2) that the adsorption of basic materials on the surface of the deposit may decrease with rise in temperature. The latter explanation may also apply to deposition from the Am bath, though there is no direct evidence for this hypothesis.

Current density

Fig. 4 shows the trend of the oxygen and hydrogen content with current density. These deposits were produced from the $S_{III}C_l$ bath at a temperature of 55° C (131° F) and a *p*H of 3. At very low current densities the oxygen and hydrogen contents of the deposits were appreciably higher than in the usual plating range of 2 to 5 amp/dm² (19 to 47 amp/ft²).

The relatively high oxygen content of the deposit obtained at a low current density was unexpected. A possible explanation was that the cathode current efficiency at 0.5 amp/dm² (5 amp/ft²), for example, might be low enough to cause an appreciable increase in the *p*H of the cathode film. This higher *p*H would increase the content of basic inclusions in the deposit. An examination of the *p*H of the cathode film by the drainage method[7,8,9], however, indicated that the *p*H was not appreciably different from that at higher current densities.

At high current densities the oxygen and hydrogen content increased and the curves showed approximately the same trend. The higher oxygen content of deposits plated at very low and very high current densities is consistent with the higher hardness of these deposits. Published qualitative data on the influence of current density on hydrogen content[3] are only partly substantiated by our findings.

pH

In Fig. 5 the oxygen and hydrogen contents of all types of deposits plated under various conditions have been averaged and plotted against the *p*H. This graph

TABLE V. CHLORIDE CONTENT OF NICKEL DEPOSITS

Bath	Temp. °C	C.D. amp/dm²	*p*H	% Cl
C	55	5	5	0.013
Ac	50	5	4.5	0.008
C-4N	55	5	3	0.014
C-4N	55	5	5	0.020
C-4N	55	10	3	0.021
C-4N	55	10	5	0.022

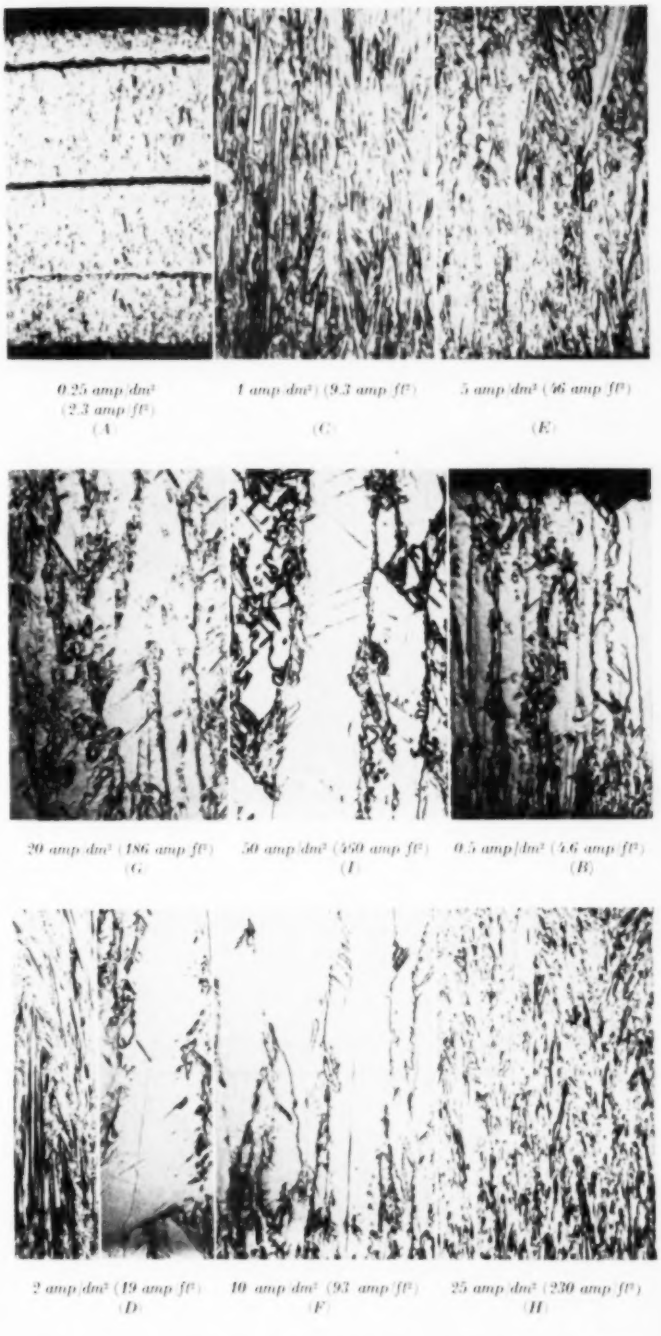
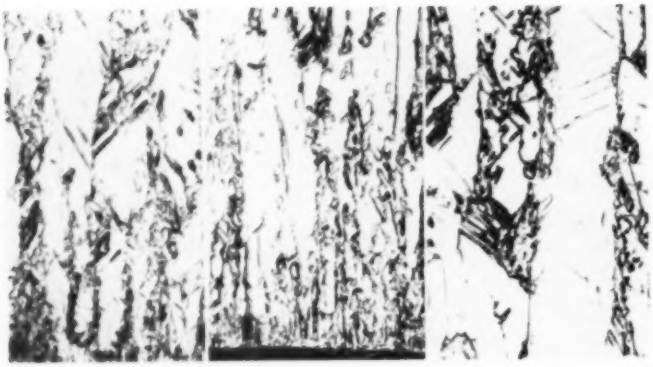
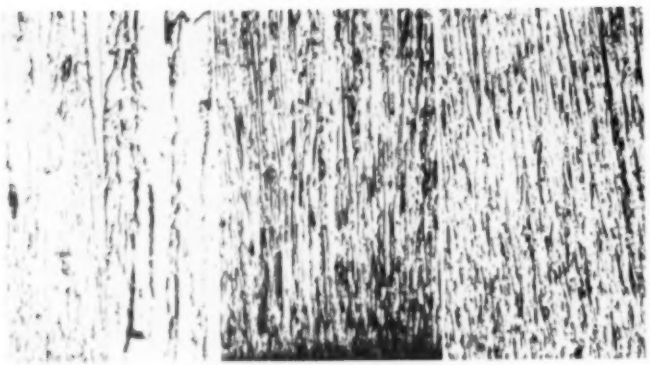

0.25 amp/dm² (2.3 amp/ft²) (A)
1 amp/dm² (9.3 amp/ft²) (C)
5 amp/dm² (46 amp/ft²) (E)
20 amp/dm² (186 amp/ft²) (G)
50 amp/dm² (460 amp/ft²) (I)
0.5 amp/dm² (4.6 amp/ft²) (B)
2 amp/dm² (19 amp/ft²) (D)
10 amp/dm² (93 amp/ft²) (F)
25 amp/dm² (230 amp/ft²) (H)

Fig. 8. Effect of current density on the structure of nickel deposited from the $S_{III}C_l$ bath at 55° C (131° F), and a pH of 3.0. Cross section x 250. Etchant: glacial acetic and nitric acid



(A) pH 1.0 (E) pH 5.0 (B) pH 1.5



(F) pH 5.5 (C) pH 3.0 (G) pH 5.7 (D) pH 4.0

Fig. 9. Effect of the pH of the plating bath on the structure of nickel deposited from the $NiSO_4$ bath at 5 amp/dm² (46 amp/ft²) and 55° C (131° F). Cross section x 250. Etchant: glacial acetic and nitric acid

TABLE VI. CARBON AND SULFUR CONTENTS OF NICKEL DEPOSITS

Bath	Temp. °C	CD amp/dm²	pH	Carbon %	Sulfur %
$oS_{II}C_1$	55	5	3	0.02	<0.001
a		6		0.05	0.083
a		3		0.016	0.058
b		6		0.02	<0.001 (semibright)
c		2		0.014	0.043
c		4		0.02	0.041
d		4		0.08	0.069
e		1.5		0.02	0.07
e		4		0.03	0.075
f	65	5	3.7	0.06	<0.001 (cobalt bright nickel)
ORH	55	5	3.5	0.03	0.028 (organic bright nickel)

demonstrates that the *p*H of the plating bath is a primary factor in determining the oxygen and hydrogen content. The oxygen and hydrogen contents increase rapidly from a *p*H of 5 upward. It will be seen later that similar curves are obtained for the variation of internal stress, hardness, and tensile strength with the *p*H. The parallel trend of oxygen and hydrogen should be noted also. The similarity of the two curves supports the view that most of the hydrogen content is derived from included basic material and not from adsorbed gas. Fig. 5 shows that the hydrogen content of deposits is higher from baths operated at a *p*H of 5 than at a *p*H of 3. If the hydrogen in the deposit came from the discharged gas, one would expect that the deposits obtained from baths of low *p*H, and hence at lower current efficiencies, would contain the most hydrogen.

C. Chloride Content

One deposit from the C bath (2N), one deposit from the Ac bath, and four deposits from the C (4N) bath were analyzed for their content of chloride, as reported in Table V. These determinations were made by R. Paulson of this Bureau. Although not enough data are on hand to show a relation between chloride content of the deposits and the bath composition or the conditions of deposition, the relatively high chloride content of these deposits is rather surprising. Without more extensive knowledge about the processes taking place in the cathode film, we can only surmise that the chloride anions are included in the deposit by the formation of basic salts. This behavior indicates that not only the cations but also the anions in nickel plating solutions have effects on the cathode deposits. Similar qualitative observations are found in the literature[28].

D. Sulfate Content

A few deposits were analyzed gravimetrically for sulfate but none was detected. These results do not confirm the statement[29] that deposits from baths containing nickel sulfate contain sulfur as sulfate.

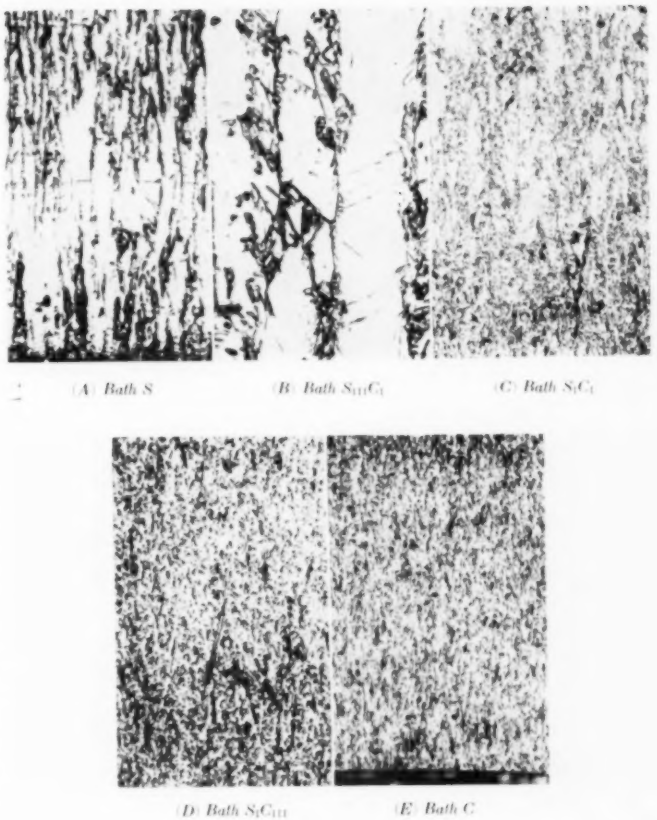
E. Carbon and Sulfur Content

The presence of carbon in both dull and bright nickel deposits has been reported by various investigators[30-33], especially in deposits prepared from solutions that contain certain organic compounds. Of our dull nickel deposits, only one produced from the $oS_{II}C_1$ bath was analyzed for carbon and sulfur, but all of the bright nickel deposits were analyzed for carbon and sulfur. These elements were determined by combustion in a manner similar to that used for analyzing steel. These determinations were made by Ch. T. Litsey of this Bureau. No systematic study was made on the effects of condi-

tions of deposition and bath composition on the carbon and sulfur content.

The interest in the carbon and sulfur content of the deposits was centered mainly in the bright deposits, because only in these deposits were appreciable quantities present. Table VI gives the values for carbon and sulfur as determined in one dull and 10 bright deposits. This range of values for the carbon content of bright nickel deposits agrees with those reported by some other observers[15], but considerably higher contents of sulfur and carbon (0.2 per cent carbon and 0.4 per cent sulfur) have been reported by others[12]. The table shows that deposits from the $oS_{III}C_1$ bath, the f bath, and the b bath contained negligible amounts of sulfur. The other deposits have appreciable amounts of sulfur, probably originating from the sulfonated organic addition agents and/or wetting agents normally used in these solutions.

The presence of sulfur, surprisingly high in some deposits, is partly responsible for the brittleness of the deposits, since those with a high sulfur content are relatively brittle in the as-deposited state and even more so after heat treatment. This is similar to the effects of sulfur present in nickel prepared by conventional metallurgical* methods. It has been observed that sulfur affects primarily the malleability of the metal, since the sulfur combines with the nickel as Ni_3S_2, which collects in the form of thin, brittle films around the crystal grains and impairs their cohesion. This sulfide also melts at a low temperature (about 630° C, 1166° F), which explains the loss of strength of sulfur-containing deposits at elevated temperatures[15].



(A) Bath S (B) Bath $S_{III}C_1$ (C) Bath S_1C_1

(D) Bath S_1C_{III} (E) Bath C

Fig. 10. Effect of increasing chloride content of the bath on the structure of nickel deposited at 55° C (131° F), 5 amp dm² (46 amp ft²), and a pH of 3.0. Cross section x 250. Etchant: glacial acetic acid and nitric acid

IV. STRUCTURE OF DEPOSITS

A. Structure by Optical Microscopy

General

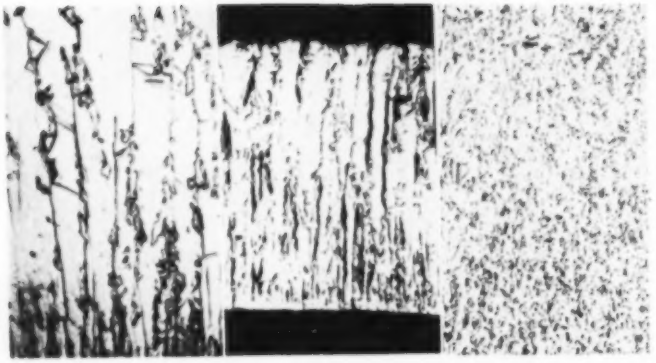
The microstructure of nickel deposits was studied in the as-deposited condition and after annealing at various temperatures. For the photomicrographs shown in this chapter the deposits were sectioned perpendicular to their surface, mounted in Bakelite, and polished. The cold-worked surface was removed with a mixture of 1 volume concentrated nitric acid, 2 volumes concentrated hydrochloric acid, and 2 volumes glycerine. To reveal the grain structure, inclusions, and voids the surface was subsequently etched with a mixture of equal volumes of concentrated nitric acid and glacial acetic acid.

Most of the photographs were made of tubular deposits, but some were made of sheet deposits. The photomicrographs were made by F. P. Brodell of the electrodeposition section.

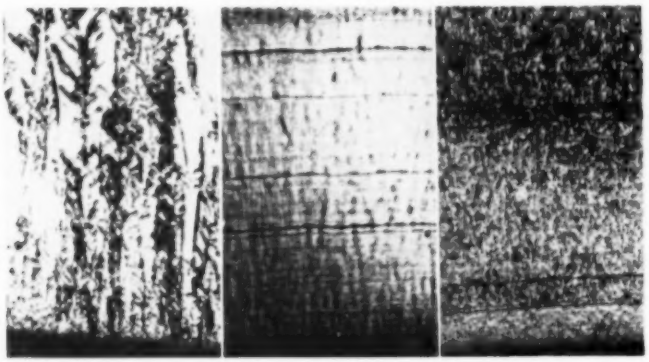
A good correlation was found to exist between the type of structure and the physical properties of the deposits. This subject will be discussed in detail in the sections on physical properties, but it may be noted here that, in general, deposits with coarse-grained structures contained relatively small amounts of impurities and were soft, ductile, and had low tensile strengths; whereas deposits with either fine-grained structures, or no visible grain structures, contained a relatively large amount of impurities and were strong, hard, and not very ductile.

Numerous references are available concerning the effects of bath composition,—including specific cations and anions,—and conditions of deposition upon the structure and physical properties but this work has not been correlated with the composition and structure of the deposits. It has been reported[12, 13] that under certain conditions of deposition two different crystal structures may appear in the same deposit, consequently, the hardness may also vary widely in the same deposit. We observed this phenomenon, especially in deposits produced at extreme conditions of temperature, current density, or pH, that is, in a transition stage where even slight changes in the operating variables may have a profound influence on the crystal structure and properties. A photomicrograph of a deposit with a duplex structure is shown in Fig. 6. This phenomenon has been described by Wesley,

*Hereafter, the word "metallurgical" is used to distinguish commercial nickel, which has been melted and cast at some step in its production, from nickel as electrodeposited.



(A) Bath Na at pH 3.0 (C) Bath NH_4 at pH 5.0 (E) Bath Am at pH 8.5



(B) Bath NH_4 at pH 3.0 (D) Bath F at pH 3.0 (F) Bath Ac at pH 4.5

Fig. 11—Nickel deposited from different types of baths at 55° C (131° F) and 5 amp/dm² (46 amp/ft²). Cross section x 250. Etchant: glacial acetic and nitric acid

In this investigation no attempt was made to study the effect of the basis metal on the structure of the deposit, although some incidental observations were made. The influence of the basis metal on the structure of the deposit has received considerable attention in the literature[22,23,28,32,34,35].

1. *Effects of Operating Variables*

Temperature

The photomicrographs shown in Fig. 7 were of specimens prepared in the $S_{III}C_I$ and $cS_{III}C_I$ baths at various temperatures, and, with one exception, at the same current density and pH. The current density of 2 amp/dm² used for deposition of specimen A was lower than that used for the others because at 10° C a current density of 5 amp/cm² did not yield a satisfactory deposit. Variations in current density between 2 amp/dm² and 5 amp/dm² have little effect on structure, as will be shown later, and the comparison of deposit A with the others is justified. A gradual change from a fine-grained columnar deposit at low temperatures to a conical and columnar coarse structure at 30° C, and especially at 55° C, is apparent. Photographs D and E are the same deposit and illustrate the influence of the buffed copper basis metal in yielding initially a fine-grained deposit. Photograph D shows the initial deposit up to a thickness of about 0.175 mm (.007 inch) and E shows the continuation of the deposit to a thickness of 0.8 mm (.032 inch). Deposit F, produced at 80° C, is much finer grained than E at 55° C. No detailed observations about the temperature effect on structure are available in the literature, but it has been observed previously[27,28] that deposits produced at low temperatures are usually finer grained than those obtained at higher temperatures. It should be noted that the structural changes shown in Fig. 7 are shown only by deposits from the $S_{III}C_I$ and the $cS_{III}C_I$ solutions obtained at a pH of 3.0. Deposits produced from the same solutions at different pH values or from different baths (Fig. 7a) show a fine-grained structure at low temperatures and a coarser-grained structure at elevated temperatures, and the unusual reversal of structure in the temperature interval from 55° C to 80° C is not observed.

Current density

Several investigators observed an influence of current density on the structure of nickel deposits[10,22,32,34,37,38].

Fig. 8 illustrates the effect of current density on the structure of deposits prepared from the $S_{III}C_I$ bath at the same temperature 55° C and pH (3.0), except that deposit I was prepared at a lower pH of 1.5. As will be shown later, variations in the pH from 1.5 to 3 do not cause a significant change in structure; therefore the inclusion of deposit I is justified. The photomicrographs in Fig. 8 show that only at extremely low and high current densities is a significant change in structure produced. Photograph A represents a deposit prepared at 0.25 amp/dm² which shows a fine-grained banded structure. Similar structures will be seen later in bright nickel deposits and in deposits from the ammoniacal bath. The occurrence of banded structures has been described[16,34] in both bright and dull nickel deposits. These banded and fine-grained structures are commonly associated with extremes in mechanical and physical properties.

Between a current density of 2 amp/dm² and 25 amp/dm² a typical columnar structure is obtained. At the extremely high current density of 50 amp/dm² a fine-grained acicular structure is found again. Two photomicrographs, G, have been included to represent successive portions of a single deposit produced at 20 amp/dm². These show the usual columnar structure and a much finer grained structure.

pH

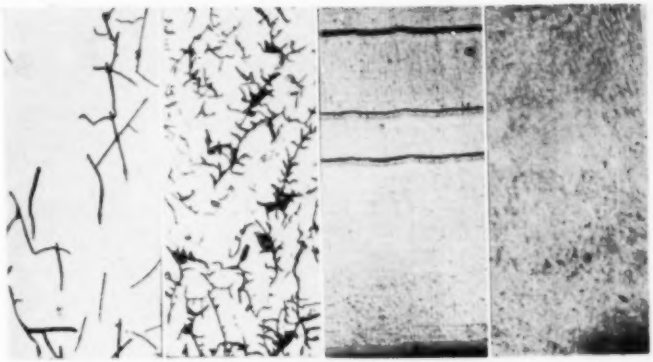
Photomicrographs of deposits (Fig. 9) produced in the $S_{III}C_I$ bath at a temperature of 55° C and a current density of 5 amp/dm², demonstrate the differences in structure brought about by varying the pH from 1 to 5.7. There is no essential change of structure in the interval from pH 1 to 5, but in deposits formed at a pH of 5.5 to 5.7 a radical alteration is apparent. These observations are in excellent agreement with the finding of other investigators who determined the influence of pH on structure[20,22,23,30,37,38]. The finer grain that occurs at a pH of 5.5 to 5.7 is probably caused by the inclusion of colloidal basic material.

2. Effect of Bath composition

It is well known that the anions in a plating solution may have an important influence on the structure and on the physical properties of electrodeposits even though they do not discharge at the cathode. Other substances, e.g., cations, such as the ammonium ion, which ordinarily do not deposit at the cathode, may also affect the deposit. To explain this phenomenon, it may be assumed that these materials affect electrodeposits by causing foreign materials to be codeposited with the metal. Dissolved materials, or their decomposition or reaction products, may be adsorbed on the freshly deposited, active metal surface and become included in the deposit. Some substances, instead of being directly adsorbed, may so modify the *p*H of the cathode film that basic compounds are codeposited with the metal, as, for example, nitrates added to a nickel plating solution. This explanation of the manner in which apparently indifferent ions or compounds are effective is supported by the presence of impurities in deposits. Chlorides are found in deposits obtained from the chloride solutions, carbon and sulfur in bright nickel deposits, and relatively large amounts of hydrogen and oxygen in deposits obtained from solutions having a high *p*H. The presence of these impurities is probably responsible for the striking differences in the structure of the deposits shown in Figs. 10 to 14.

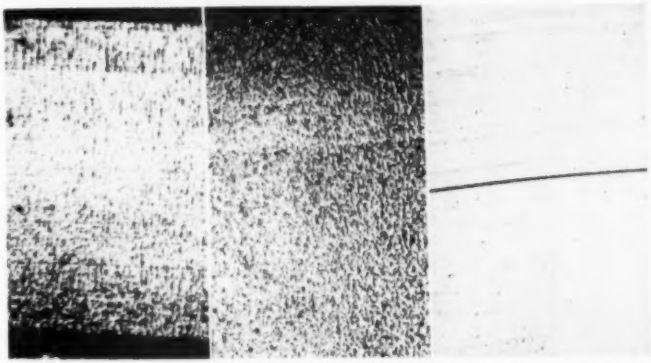
Fig. 10 depicts the effects on the structure of deposits caused by increasing the ratio of nickel chloride to nickel sulfate in the bath. All of these deposits were produced under the same conditions from the baths indicated. Deposits from an all-sulfate bath (Fig. 10A) show a slightly banded and somewhat finer columnar structure than does the deposit from the $S_{III}C_I$ bath (Fig. 10B) which is the coarsest. With increasing chloride content of the solution the grain size becomes finer, and deposit E from the all-chloride bath C has the finest grain structure. The gradual transition from the columnar to the fine-grained structure is very clearly illustrated in these photomicrographs. For instance, some columnar fragments can still be detected in the deposit from the S_IC_I bath (Fig. 10C), but in Fig. 10D these could not be found. The effect of the chloride ion in producing fine grains has been reported by several other investigators[20, 24, 27, 28, 121, 122, 124, 140].

The structures of deposits obtained from baths of various compositions, and in particular from the $S_{III}C_I$ bath to which special additions had been made, are illustrated in Fig. 11. Additions of small quantities of sodium sulfate to the $S_{III}C_I$ bath have no effect on the struc-

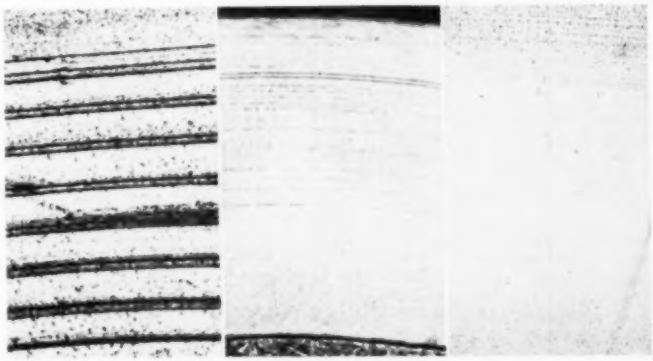


at 25° C (77° F) and 2 amp/dm² (19 amp/ft²) (A) — *at 25° C (77° F) and 5 amp/dm² (46 amp/ft²) (B)* — *at 55° C (131° F) and 7 amp/dm² (65 amp/ft²) (C)* — *at 80° C (176° F) and 5 amp/dm² (46 amp/ft²) (D)*

Fig. 12. Nickel deposited from the Am bath at a pH of 8.5. Cross section x 250. Etchant: glacial acetic and nitric acid



Bath f at 65° C (149° F), 5 amp/dm² (46 amp/ft²), pH 3.6 (A) — *Bath ORT at 55° C (131° F), 5 amp/dm² (46 amp/ft²), pH 3.5 (B)* — *Commercial deposit a at 40 amp/ft² (C)*



Commercial deposit c at 30 amp/ft² (D) — *Commercial deposit d at 35 amp/ft² (E)* — *Commercial deposit e (F)*

Fig. 13. Bright nickel deposits. Cross section x 250. Etchant: glacial acetic and nitric acid

TABLE VII.—RELATION BETWEEN X-RAY STRUCTURE OF NICKEL DEPOSITS AND SOME MECHANICAL AND PHYSICAL PROPERTIES

Expt. No.	Bath	Temp. °C	C.D. amp./dm.²	pH	Finish	Grade of diffuseness	Cryst. size estimated microns	Degree of fibering $H_{\perp}$ / $H_{\parallel}$	Degree of fibering $H_{\perp a}$ / $H_{\parallel a}$	Preferr. orientation texture	Hardness Vickers	Tensile strength lb./in.² × 10³	Tensile strength kg./mm.²	Resistivity microhm-cm	Total impurities content	Photomicrograph structure
1	$NiCl_2$	30	5	3	dull	B	< 0.1	38.6		[100]	182	75	52	7.83	0.009	columnar, finer than 2
2		55	5	3	dull matte	A	0.1	9.2		[100]	150	56	39	7.76	0.023	coarse columnar
3	$nNiCl_2$	55	5	3	dull matte	A	0.1	8.2		[100]	142	60	42	7.44	0.011	coarse columnar
4	C	55	5	5	dark dull	C	0.01	0.4	1.33	[111] & [110]	321	135	95	8.93	0.143	fine grained
5	Ac	50	5	4.5	dull	E	0.01	5.2		[100]	335	147	103	9.18	0.026	fine grained, slight laminations
6	a		6		bright	F	0.01	0.5	5.0	random	617	222	155	11.00	0.152	very fine grained and laminated
7	b		6		semibright	E	0.01	6.6		[100]	280	130	91	8.27	0.036	fine grained
8	c		4		bright	G	0.01	1.7		[100]	572	220	154	13.03	0.072	very fine grained and laminated like No. 6
9	d		4		bright	G	0.01	0.9		[100]	619	227	159	18.93	0.167	very fine grained and laminated like No. 6
10	e		4		bright	G	0.01	0.4		[111] & [100]	437	191	134		0.128	very fine grained and laminated like No. 6
11	f	65	5	3.7	bright	F	0.01	5.5		[100]	509	202	141	11.49	0.077	very fine grained, less laminated
12	OBT	55	5	3.5	bright	G	0.01	2.0		[100]	496	212	148	10.00	0.064	very fine grained, less laminated
13	compressed nickel powder							0.5	2.1							

ture (compare 11A and 10B). A finer grain is produced by adding ammonium sulfate to the $S_{III}C_1$ bath (compare 11B and 10B), but this effect is much more pronounced at a *p*H of 5 (compare 11C and 9E). This effect of ammonium sulfate has been described previously[77,108]. A deposit from a fluoborate bath resembles closely in structure and physical properties a deposit from a $S_{III}C_1$ bath (compare 10A and 10B). Very interesting banded and fine-grained structures can be seen in 11E (from an ammoniacal bath) and 11F (from a chloride acetate bath).

As compared with the Watts bath, the profoundly different type of structure, and consequently difference in physical properties, of deposits produced from an ammoniacal bath is accompanied by the highest oxygen and hydrogen content found in any of the deposits; (see Table IV, No. 63-66). The influence of these impurities in producing fine grains can be seen readily in Fig. 12 which shows 4 photomicrographs of deposits produced at different temperatures from the ammoniacal nickel bath, Am. The deposits A and B are interesting because they are similar to electrolytic chromium and to deposits obtained from the Watts bath at a high *p*H of 5.9 and 6[57,182,209]. These deposits have no crystal structure visible under the microscope and are permeated by fine cracks, probably filled with inclusions. It is noteworthy that the oxygen content of these deposits approaches that of electrolytic chromium and their hardness is around 550 VHN. Deposit 12C with its banded structure resembles closely the bright nickel deposits, shown in Fig. 13. Nickel deposits with a high content of foreign inclusions, i. e., the Am and the bright nickel deposits, are similar in crystal structure and in physical properties even though the inclusions are chemically different.

The six photomicrographs in Fig. 13 demonstrate the typical banded or laminated, extremely fine-grained structure of bright nickel deposits. These features of their structure are well known[116,168,169,173]. The grain size in most cases is so fine that it cannot be resolved by the microscope. The physical properties that accompany this type of structure are quite different from those of ordinary dull nickel deposits. In Fig. 13A (deposit from a cobalt bright nickel bath) both a directional growth and a banded structure are observable. With the exception of A and B in Fig. 13, deposits show only laminations and no grain structure.

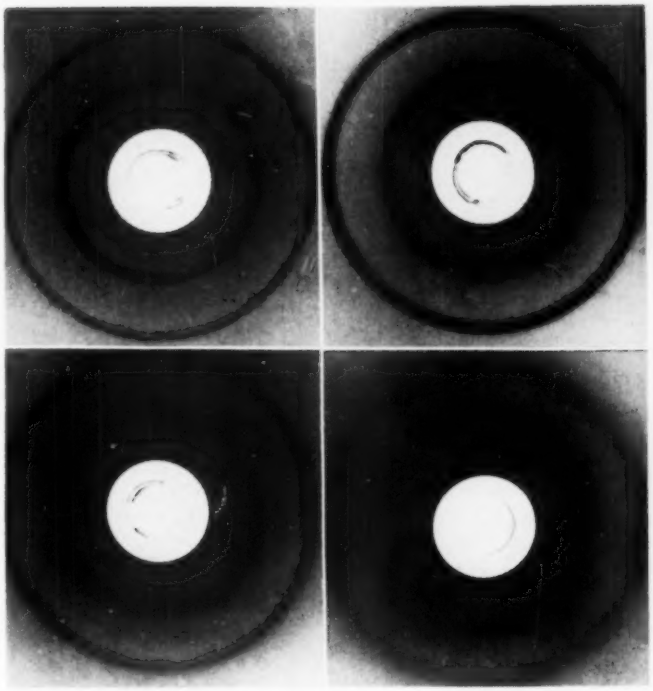


Fig. 14. Back reflection X-ray patterns of nickel deposits illustrating different degrees of diffuseness and line broadening

Top, left: deposit from $S_{III}C_1$ bath at 55° C (131° F), 5 amp/dm² (46 amp/ft²), and pH of 3.0

Top, right: deposit from C bath at 55° C (131° F), 5 amp/dm² (46 amp/ft²), and pH of 5.0

Bottom, left: deposit from Ac bath at 50° C (122° F), 5 amp/dm² (46 amp/ft²), and pH of 4.5

Bottom, right: deposit from OBT bath at 55° C (131° F), 5 amp/dm² (46 amp/ft²), and pH of 3.5

B. Structure Observed By Other Methods

1. X-ray Diffraction

The structure of nickel electrodeposits, as revealed by X-ray and electron diffraction[80-97], has been the subject of several investigations. The presence of a fibrous, preferentially oriented structure in most nickel deposits has been shown[21,22,26,31,116,122,136,172]. It was formerly believed that a relation existed between the brightness of a nickel deposit and the preferred orientation of its crystals[72], but later work did not support this assumption[116,198]. The presence of a hexagonal close-packed structure, either alone or in combination with the usual face centered cubic structure under certain conditions of deposition, has been reported in nickel deposits[120,210].

Diffraction patterns were obtained on 12 specimens of electrodeposited nickel in the effort to indicate the degree of size-strain, the textures present (preferred orientation), and their degree of orientation. The samples were cut from electroformed sheets. The conditions of deposition and the bath compositions are shown in Table VII. The X-ray diffraction studies were made by H. C. Vacher of the Metallurgy Division of this Bureau.

Degree of size-strain

Back reflection patterns were obtained from each side of the nickel specimens with copper K-alpha radiation and the diffuseness and broadening of the lines were rated on a relative scale. It is noteworthy that the pattern obtained from the side of the deposit, initially adjacent to the stainless steel base, was usually more diffuse than that obtained from the side adjacent to the electrolyte. This illustrates the well-known effect of the basis metal in retarding the development of a characteristic structure in the initial deposit[22,32,80].

The diffuseness in X-ray diffraction patterns may result from two causes: small crystal size and lattice distortion. The term "size-strain" expresses the result of

Fig. 15. Electron-micrograph of nickel deposited from the $S_{111}C_1$ bath at 55° C (131° F), 5 amp/dm² (46 amp/ft²), and a pH of 3.0. Magnification—33,600. Electron beam transmitted through a film of nickel one millionth of an inch thick

these two factors. In back reflection patterns the amount of diffuseness contributed by each of these causes cannot be distinguished. The diffuseness of the patterns was rated by comparison with the arbitrarily selected specimens, A, C, E, and G illustrated in Fig. 14, which represent a progressive decrease in crystal size or an increase in lattice distortion or both. The intermediate ratings of B, D, and F were estimated. The inner double rings are composed of reflections from (420)-planes and the outer from (333)-planes.

The data in Table VII show that the degree of diffuseness of the deposits parallels the trend in some of the physical and mechanical properties. Thus, the deposits from the $S_{111}C_1$ bath (Nos. 1, 2, and 3) have the sharpest patterns, which were rated as A and B. These deposits have the lowest hardness, tensile strength, resistivity, and content of impurity of any of the specimens included in the table. The patterns of the bright nickel deposits (Nos. 6 to 12) were the most diffuse and were rated as G and F. These deposits had a much higher hardness, tensile strength, resistivity, and total content of impurities than the Watts deposits. The patterns of the deposits from the C and the Ac baths (Nos. 4 and 5) had an intermediate degree of diffuseness and the physical and mechanical properties of the deposits were likewise intermediate between the Watts deposits and the bright nickel deposits. The diffuseness of the patterns also correlates with the photomicrographs of these deposits—the Watts deposits, which have the largest grain size, gives the sharpest diffraction rings, whereas the bright nickel with submicroscopic grain size yields diffuse patterns. It is obvious that the deposits with the smallest grain size, as determined from photomicrographs and from the diffuseness of the X-ray diffraction pattern, are also the brightest deposits. These conclusions differ from those of Clark and Simonsen[124] who state that "The property of brightness in nickel deposits is not due largely to grain size, as the X-ray grain sizes of matte, semibright, and bright nickel electrodeposits were found to be of the same order of magnitude."

Textures present

In many electrodeposited metals a tendency for crystals to grow in such a manner that certain crystal planes are perpendicular to the direction of growth, that is, parallel to the plane of the cathode, has been noted. This tendency is manifested by a type of preferred orientation frequently referred to as fiber texture. Diffraction patterns of the nickel deposits were obtained by using a cylindrical camera with the collimated beam inclined to the surface of the specimen at 10° and 25°. Unfiltered radiation from a cobalt target was used. An analysis of the pattern was made, following conventional practice[114,125] by noting the intensity maxima in reflection circles of stereographic projections. Most of the deposits showed a preferred orientation. The textures are shown in Table VII, column 11. Two deposits, Nos. 4 and 10 from baths C and e, showed a double texture, but all other deposits, both bright and dull, had a [100] texture, with the exception of bright deposit "a" (No. 6) which had a random orientation. In agreement with these findings a recent investigation[126] showed that there is no over-all relation between preferred orientation and brightness of nickel deposits.

Degree of fiber texture

An index to the degree of fiber texture was obtained with the aid of a Norelco Geiger-counter spectrometer. The geometry of the spectrometer is such that the relative intensity of reflections from (111), (100), and (110) planes in crystals irradiated by the beam of X-rays can be measured conveniently. The angles between the reflections and between the crystallographic planes are such that it is impossible for one crystal to contribute to more than one reflection. Therefore, there is a direct relation between the relative intensities and the number of crystals having orientations required by the geometry of the spectrometer. This means that a strong 200-reflection in combination with weak 111- and 220-reflections would indicate a [100] fiber texture.

In order to get a comparison of values for the relative intensities of the 111-, 200-, and 220-reflections in terms of degree of fiber texture they were compared to similar values obtained from a specimen of nickel powder in which the crystals were oriented randomly. This specimen was a disk, 1 inch (2.5 cm) in diameter by 0.25 inch (0.63 cm) thick, made by compressing nickel powder under a 100,000 lb (45,500 Kg) load. The 200-reflection was made relative to the 111- and 220-reflections, that is, the ratios $\frac{I_{200}}{I_{111}}$ and $\frac{I_{200}}{I_{220}}$ were determined for each specimen. The peak heights in the spectrometer charts were used as a measure of intensity, care being taken to operate the spectrometer as nearly as possible under reproducible conditions.

The two ratios $\frac{I_{200}}{I_{111}}$ and $\frac{I_{200}}{I_{220}}$ are shown in Table VII for the twelve nickel speci-

mens and for the compressed nickel powder specimen. Values for the $\frac{I_{200}}{I_{220}}$ ratio were reported for two specimens (Nos. 4 and 6 in Table VII), because the peak heights for the 220-reflection obtained from these specimens were significantly large. Specimens that gave the insignificant 220-reflections and values for the $\frac{I_{200}}{I_{111}}$ ratio greater than 0.5 (the value for the randomly oriented specimen) were considered as having a degree of [100] fiber texture in proportion to the $\frac{I_{200}}{I_{111}}$ ratio.

Specimen No. 4 has a weak [110] fiber texture, as indicated by the spectrometer, and a weak [111] fiber texture also, according to the data obtained with the cylindrical camera. Both methods of measurement indicated that specimen No. 10 had a [111] texture; in addition, the cylindrical camera indicated a [100] texture. The value of 0.5 for the $\frac{I_{200}}{I_{111}}$ ratio indicated a random orientation for specimen 6. This was confirmed with patterns obtained with the cylindrical camera.

A [110] fiber texture was reported recently[20] for a deposit similar to our specimen No. 4, Table VII.

2. *Electron Microscopy*

The structure of a nickel deposit from the $S_{III}C_I$ bath (deposit No. 39, Table I) was observed with the aid of RCA-Type EMU 50 kv electron microscope by M. Swerdlow of the Mineral Products Division of this Bureau. The deposit was produced as a film about 0.000.002 cm (0.000.001 inch) thick by depositing it on a thin copper layer which had been plated on a stainless steel cathode. After the nickel was deposited, it was covered with a plastic layer for protection and the copper film was peeled from the cathode. Subsequently the copper was dissolved in a mixture of chromic and sulfuric acids, leaving the very thin nickel foil reinforced by the plastic. Before examining the metallic film the plastic backing was removed and small pieces of the nickel film were picked up on the 1/8 inch specimen screens and dried flat. Fig. 15 was obtained by transmitting the electron beam through the nickel foil. The transmission electron micrograph shows some straight sided crystals which have been interpreted as being cubic, some twinned crystals, and a number of small transparent and opaque (light and dark) areas which are probably pores and inclusions. It is believed that the outlined area (center of picture) represents a crystal oriented in the plane of the film. Electron photomicrographs of surface replicas have been published previously by others, but they did not show any structure of this type.

The possibility that this crystal orientation may have been induced by the structure of the copper substrate should not be overlooked.

TABLE VIII. EFFECT OF TEMPERATURE OF THE PLATING BATH AND OF CURRENT DENSITY ON CATHODE CURRENT EFFICIENCY

Expt. No.	Bath	Temp. °C	Current density amp/dm²	pH	Cathode Efficiency %
			Temperature		
1	$S_{III}C_I$	20	5	3	100
2	$S_{III}C_I$	55	5	3	99
3	$S_{III}C_I$	80	5	3	100
4	$S_{III}C_I$	30	5	1.5	77
5	$S_{III}C_I$	55	5	1.5	89
6	$S_{III}C_I$	80	5	1.5	99
			Current Density		
7	$S_{III}C_I$	55	0.25	3	96
8	$S_{III}C_I$	55	0.50	3	97
9	$S_{III}C_I$	55	1	3	99
10	$S_{III}C_I$	55	2	3	100
11	$S_{III}C_I$	55	5	3	99
12	$S_{III}C_I$	55	10	3	100
13	$S_{III}C_I$	55	15	3	99
14	$S_{III}C_I$	55	25	3	99
15	S_IC_I	55	0.50	3	88
16	S_IC_I	55	1	3	90
17	S_IC_I	55	2	3	98
18	S_IC_I	55	25	3	100

V. MEASUREMENTS RELATED TO THE PLATING PROCESS

A. Cathode Efficiency

The cathode current efficiency at which a deposit is produced does not have any direct effect upon its physical or chemical properties. No evidence exists to show that deposits produced at low current efficiencies contain increased contents of hydrogen, as might have been predicted. Most of the nickel deposits studied in this investigation were produced at high cathode current efficiencies. Small variations in efficiency had no apparent effect on the physical properties of the deposits.

The cathode current efficiencies were measured by the increase in weight of a cathode consisting of a gold rod. No at-

TABLE IX. EFFECT OF THE *p*H OF THE PLATING BATH ON CATHODE CURRENT EFFICIENCY

Expt. No.	Bath	Temp. °C	Current density amp/dm²	pH	Cathode efficiency %
1	$S_{III}C_I$	55	5	1	80
2	$S_{III}C_I$	55	5	1.5	89
3	$S_{III}C_I$	55	5	3	99
4	$S_{III}C_I$	55	5	4	97
5	$S_{III}C_I$	55	5	5	98
6	$S_{III}C_I$	55	5	5.5	99
7	NH_4	55	5	1.5	87
8	NH_4	55	5	3	100
9	NH_4	55	5	5	99
10	NH_4	55	5	5.5	100
11	C	55	5	1.5	98
12	C	55	5	3	100
13	C	55	5	5	100
14	C	55	5	5	100

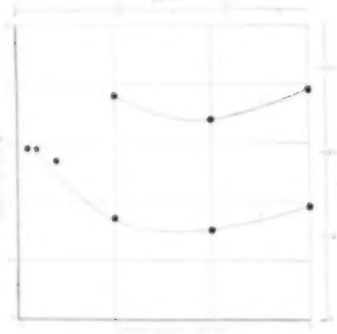


Fig. 16. Effect of current density on the stress of nickel deposited at 55° C (131° F) and a pH of 3.0
Curve 1—S_1C_{111} bath
Curve 2—$S_{111}C_1$ bath

tempt was made to attain high precision. Usually a stop watch and a calibrated ammeter were used for the determination of time and current, but in a few experiments a copper coulometer was inserted in the circuit. The measurements were probably accurate to about one per cent. The electrolyte used in the coulometer contained 190 g of copper sulfate ($CuSO_4 \cdot 5H_2O$), 75 g of concentrated sulfuric acid and 75 g ethyl alcohol in 1 liter of solution.

The effects of temperature and current density on the cathode current efficiencies are shown in Table VIII. Only at a low *p*H (1.5) did the temperature have a marked effect (expt. 4 to 6). Above a *p*H of 3 the cathode efficiencies were practically 100 per cent between 20° and 80° C (expt. 1 to 3). The effect of current density on the cathode current efficiency of a $S_{111}C_1$ and a S_1C_1 bath was also slight. Only current densities below 1 amp/dm² had an effect (expt. 7, 8, 15, 16). At low current densities the cathode current efficiencies were lower in the S_1C_1 (expt. 15 and 16) than in the $S_{111}C_1$ (expt. 8 and 9) bath under identical plating conditions.

The data in Table IX illustrate the small influence of *p*H on cathode current efficiencies in the $S_{111}C_1$, NH_4, and C baths. The cathode efficiency was decreased only in the low *p*H range of 1 to 2 (expt. 1, 2, and 7), while at or above a *p*H of 3 the current efficiencies were practically 100 per cent. At a *p*H of 1.5 the current efficiency in the $S_{111}C_1$ bath dropped to about 90 per cent (expt. 2), but the cathode efficiency in the C bath remained close to 100 per cent (expt. 11).

B. Internal Stress

General

The existence of internal stresses in electrodeposited nickel has been known for many years[1,2,3,4,5]. There are a number of theories to explain this phenomenon. Some investigators believe that the codeposition and inclusion of hydrogen, or the formation of nickel hydrides and their consequent decomposition, is responsible for the occurrence of stress in nickel deposits[4,8,9,21,23]. Others have held that (1) nickel hydroxide or basic salts that may be present as colloids in the cathode film, or (2) metallic contamination is responsible[10,132]. The formation of a distorted metallic lattice at a low temperature has also been considered as a cause of high internal stresses[11,181]. It seems probable that the stress within an electrodeposit may be caused by a number of different factors.

The presence of stress is of concern in commercial electrodeposition since it may be responsible for the peeling or cracking of nickel deposits and for the distortion of items formed from thin sheet metal. In nickel electroforming, stress is one of the most important factors since the dimensional accuracy of an electroformed article and its performance in use may be affected by stress. Stress was a practical consideration in this study because stressed deposits tend to crack and pull away from the stainless steel cathode or to warp so badly that the current distribution is not uniform. Some apparently sound nickel deposits on copper tubes cracked when the copper was dissolved leaving fragments instead of a tube. In general, the coherence of a tubular deposit when stripped from its copper base gave a good indication of the amount of internal stress present. For instance, it was impossible to produce sound nickel tubes from a $S_{111}C_1$ bath at a *p*H of 5.8 or from a C bath at a *p*H of 5.5 since such tubes would invariably crack when the basis metal was removed.

Interest in the measurement of stress in electrodeposited nickel and other metals has led to methods for measuring quantitatively this important property[17,49,141,170,181,183,187]. In this study extensive use was made of the spiral contractometer developed by Brenner and Senderoff[188]. The stress during deposition was determined for most of the solutions and conditions of plating used in this investigation, and an effort was made to correlate stress with conditions of deposition and the physical properties of the deposit.

The method of using the spiral contractometer for the determination of stress during deposition has been fully and adequately described[188]. As it has been reported[49,50] that the crystal structure of the basic metal may affect the stress in the deposit up to certain thicknesses, the procedure was adopted of copper plating the stainless steel helix before making the stress measurement in order that the deposit should always be laid down on a reproducible surface. For comparative purposes stress measurements must be based upon equal thicknesses of deposit, since the stress may vary considerably with thickness. The results of stress given in this paper are for deposits 0.0075 mm (0.0003 inch) thick. The reproducibility of these stress measurements was not high, being of the order of 20 per cent. This somewhat low reproducibility probably was partly a consequence of instrumental errors and partly of the sensitivity of the measurement to slight variations in composition, such as slight contamination of the plating solution by organic and inorganic substances.

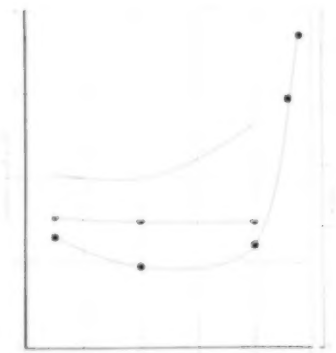


Fig. 17. Effect of pH of plating bath on stress in nickel deposited at 5 amp/dm² (46 amp/ft²)
Curve 1—baths C, dC, $C(-5N)$ at 30° C (86° F) to 80° C (176° F)
Curve 2—baths S_1C_1, S_1C_{111}, NH_4 at 55° C (131° F)
Curve 3—baths $S_{111}C_1$, $nS_{111}C_1$ at 55° C (131° F)

1. Relation of Stress to Plating Variables

Temperature of deposition

No detailed analysis of the data on the variation of stress with temperature will be made here since many of the variations in stress resulting from changes in the temperature of the plating solution were within the experimental error. The results are in general agreement with the numerous references dealing qualitatively with the effect of bath temperature on stress[3,4,6,7,12,27,141,156,179].

Two different trends of stress with temperature of the plating solution were observed: (a) the stress in deposits from solutions high in chloride, such as the S_1C_{III} and the C baths, decreased with increase in temperature (also reported in[3,4,6,7]); (b) the stress in deposits from the Watts type solutions ($S_{III}C_I$, Na, NH_4) was a minimum at 55° C. The latter is in accord with published accounts in the literature[178,187], except that the minimum found by Phillips and Clifton[178] was less pronounced.

Current density

The variation of stress with current density in the customary plating ranges was slight and probably within the experimental error. Only at the extremes of the current density range did an appreciable increase in stress occur, as shown in Fig. 16 for the $S_{III}C_I$ and the S_1C_{III} baths. These results confirm the work of Phillips and Clifton[178] and Hothersall[187], with but minor differences. Phillips and Clifton found more change in the interval between 5 and 15 amp/dm² and less change in the interval of 2 to 5 amp/dm² than in the current investigation. Hothersall found little variation of stress in the range of 0.5 to 1.5 amp/dm², but this is too narrow a range to show a significant change. He did find that the stress was markedly increased at very low current densities.

2. Effect of Bath Composition

It is well known that the stress in nickel deposits is markedly affected by the composition of the plating solution and the *p*H[1,7,12,139,141,156,179]. As an example of the effect of the composition, it was found that the stress ranged from about 20,000 lb/in² for deposits from the Watts solution (curve 3, Fig. 17) to about 40,000 lb/in² for deposits from the chloride solution (curve 1, Fig. 17). The points on the curves in Fig. 17 were obtained by averaging the stresses obtained in two or more plating solutions under different conditions, as indicated in the legend.

Effect of pH

Within the recommended range of *p*H for different types of baths, which is between 2 and 5 for the Watts type and 2 and 4 for the chloride type, it is evident from Fig. 17 that the stress in the deposit did not change appreciably. However, the data for the Watts bath (curve 3) show that the stress increases markedly as the *p*H of the solution is raised above the customary working range. This confirms similar observations of Martin[141]. Data were not obtained in the high *p*H range for the other solutions, but there is no doubt that the stress would similarly increase. This increase in stress probably is caused by the codeposition of basic material.

The minimum observed in curve 3 for the Watts type solutions is rather slight but may be real as it has been reported previously by others. Soderberg and Graham[26] reported a minimum stress at a *p*H of 3; Phillips and Clifton[178] and Martin[141] at a *p*H of 4. In general the *p*H of 3 in the Watts type plating solutions seems to be a critical point because, as will be seen later, many of the values for the mechanical and physical properties of deposits plated at this *p*H are either at a minimum or a maximum.

Nickel chloride content

Fig. 18 shows the dependence of stress on the content of nickel chloride in the solution. On the abscissa are marked the solutions in increasing order of their chloride content, that is starting with the S bath which has no chloride and ending with the C bath which is 100 per cent chloride. The points on this curve were obtained by averaging the stress values for deposits obtained at 55° C, a current density of 5 amp/dm², and a *p*H ranging from 1.5 to 5.0. The curve shows that the stress increased steadily with increasing nickel chloride content of the solution. The stress-raising properties of the chloride anion have been recognized and described in the literature[139,141,179,181,183,185]. How the content of the chloride anion influences the stress is not easily answered with our present knowledge of the plating process. Vuillemier[12] has suggested that the stress in a deposit depends on the structure. This idea may have some bearing on stress in deposits from baths containing chloride since, as the chloride content increases, the structure of the deposits becomes finer grained (see Fig. 10) along with the increase of stress. However, it is more likely that stress and structure are not directly related but are caused by the same factors.

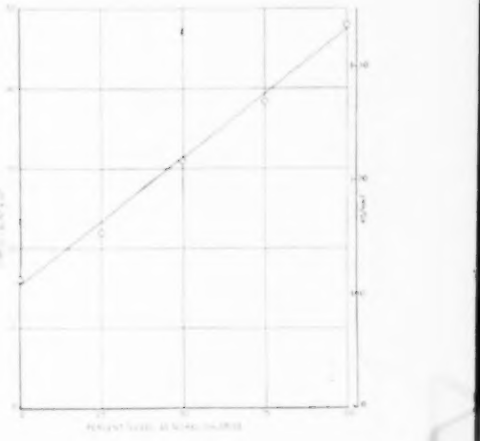


Fig. 18. Variation of stress of nickel deposits with chloride content of plating solutions. Deposits obtained at 55° C (131° F) and 5 amp/dm² (46 amp/ft²) from the following bath:

S	*pH 1.5 and 3.0*
$S_{III}C_I$	*pH 1.5, 3.0, and 5.0*
S_1C_I	*pH 1.5, 3.0, and 5.0*
S_1C_{III}	*pH 1.5, 3.0, and 5.0*
C	*pH 1.5, 3.0, and 5.0*

Nickel content

Table X shows that the stress in the deposit increases slightly with increasing metal content of the solution, but considering the precision of the measurements, this tendency may not be too significant. Martin[141] made observations from which he concluded that changes in the nickel concentration from 7.8 oz/gal

TABLE X. EFFECT OF NICKEL CONTENT ON STRESS

Bath	Temp. °C	C.D. amp/dm²	*p*H	Stress lb/in² × 10³	Vickers Hardness
$S_{III}C_I$-1N	55	5	5	19.5	160
$S_{III}C_I$	55	5	5	24.3	160
$S_{III}C_I$-4N	55	5	5	27.7	289

TABLE XI. DENSITY OF NICKEL DEPOSITS AND THEIR OXYGEN, HYDROGEN, AND TOTAL IMPURITIES CONTENT

Expt No.	Bath	Temp. °C	C.D. amp/dm²	pH	Density g/cm³	Oxygen % weight × 10⁴	Hydrogen % weight × 10⁴	Total impurities % weight × 10⁴
1	$NiSO_4Cl_2$	10	2	3	8.89 tube	10	7	17
2		55	0.25	3	8.90 tube	63	4	67
3		55	0.50	3	8.91 tube	32	0	32
4		55	2	3	8.92 tube	2	0	2
5		55	5	3	8.90 tube	23	0	23
6		55	5	5.5	8.90 tube	43	7	50
7		55	5	5.6	8.87 tube			
					8.92 sheet	65	2	67
8		55	25	3	8.89 tube	53	5	58
9	nSO_4Cl_2	55	5	3	8.91 tube	11	0	11
10	SO_4Cl_2	55	5	3	8.91 tube	17	2	19
11		55	5	5	8.91 tube	26	3	29
12	NH_4	55	5	3	8.90 tube	12	0	12
13	Na	55	5	3	8.91 tube	9	1	10
14	C	55	5	3	8.90 tube	11	1	12
15		55	5	5	8.84 tube			
					8.91 sheet	117	12	142 plus chlorine
16	Ac	50	5	4.5	8.90 tube	16	1	26 plus chlorine
17	SO_4Cl_2	55	5	3	8.90 tube	26	2	28
18	S	55	5	4.5	8.91 tube	14	1	15
19		55	5	3	8.92 tube	30	1	31
20	F	55	5	3	8.91 tube	10	1	11
21	C, N	55	5	3	8.86 tube	46	10	70 plus chlorine
22		55	5	5	8.85 tube	73	10	103 plus chlorine
23		55	10	3	8.85 tube	50	6	77 plus chlorine
24		55	10	5	8.82 tube	73	13	108 plus chlorine
25	Am	25	5	8.5	8.45 tube	230	22	302
26		55	2	8.5	8.62 tube	61	14	75
27		55	7	8.5	8.77 tube	77	22	99
28		80	5	8.5	8.82 tube	42	9	51
29	a		3		8.82 tube	10	1	85 plus carbon and sulfur
30			4		8.66 tube			
31			6		8.87 sheet	15	4	152 plus carbon and sulfur
32	c		2		8.92 sheet	7	1	65 plus carbon and sulfur
33			3		8.88 tube			
34			4		8.92 sheet	10	1	72 plus carbon and sulfur
35	d		3.5		8.62 tube			
36			4		8.88 sheet	16	2	167 plus carbon and sulfur
37	e		1.7		8.91 sheet	11	3	104 plus carbon and sulfur
38			4		8.89 sheet	18	5	128 plus carbon and sulfur
39					8.83 tube			
40	f	65	5	3.7	8.90 tube	14	2	76 plus carbon and sulfur
41	OBT	55	5	3.5	8.86 tube			
42		55	5	3.5	8.92 sheet	5	1	64 plus carbon and sulfur

(58 g/l) to 13.7 oz/gal (103 g/l) do not have any appreciable effect on the stress in the deposits.

Other additions

Other constituents besides chloride which are normally added to the plating solution may increase the stress in the deposit[4,84,130,161,178]. No detailed study of such additions was made but some of the observations are worthy of note. The addition of ammonium salts to a Watts-type solution (both NH_4) increased the stress in the deposit, whereas Martin[93] reported a reduction in stress. The increased stress which was found is consistent with the other properties of the deposit; this deposit was finer grained and harder than the deposit from the Watts plating solution.

Organic addition agents are known to have a large effect on the stress in a nickel deposit[9,7,118,150,179,181,185]. They may increase the stress, but some of them decrease the stress and may even convert it from a tensile stress to a compressive stress. In particular, the addition of nickel benzene disulfonate caused a complete reversal of the stress in the $SnCl_2$ solution. This phenomenon had been described previously[18].

3. Relation Between Stress and Oxygen and Hydrogen Content of Deposits

No general relation was found between the stress and the oxygen and hydrogen content of nickel deposits. However, if the study is restricted to a narrower field, such as the deposits from a single plating solution, it is found that an increase in stress is accompanied by an increased

content of oxygen and hydrogen in the deposit. Thus, the deposits obtained from the $S_{III}C_I$ bath at the extremes of current density (curve 2, Fig. 16) and at the highest *p*H (curve 3, Fig. 17) have relatively high stresses and high oxygen contents (see Table I).

VI. DENSITY

In previous studies of the physical properties of chromium[42], the density was found to be related to the oxide content of the deposits and to certain of their physical properties. The densities of the nickel deposits, however, showed relatively little variation and therefore were not so readily correlated with other properties of the deposits.

The density of the nickel deposits was determined at about 25° C by the method of loss in weight using tetrabromoethane (density 2.9474 g/ml at 28.7° C), the density of which had been accurately measured by the Capacity and Density Section of this Bureau. The coefficient of cubical expansion of this liquid (0.00223 per degree centigrade) was used to correct all density determinations to 25° C. The precision of the density determinations was about 1 part in 500.

For comparison with the density of electrodeposited nickel, it is of interest to have a representative value for the density of nickel which has been subjected to metallurgical treatments. The density of commercial nickel varies according to its composition, physical condition, and mechanical treatment[3]. The values in the literature range from 8.70 to 8.90[3,10,19,49,59]. The figures considered by Wise and Schaefer[59] as most reliable are as follows: cast metal 8.907 g/cm³, worked and annealed metal 8.900 to 8.903 g/cm³[3,194]. The density of nickel, calculated from its lattice constant (3.5168 kX-units), is 8.91 g/cm³. For this calculation Avogadro's number was taken as 6.02×10^{23} and the atomic weight of nickel as 58.69.

Examination of the data in Table XI shows that the density of most of the Watts-type nickel deposits is very close to the value for pure nickel. A large difference in density would not be expected because of the rather high purity of the electrodeposited nickel. A calculation shows that the lowering of the density caused by the presence of 0.1 per cent of oxygen in the form of NiO would be only about 0.01 g/cm³, which is about the limit of the precision of the density measurement.

Another factor must be taken into consideration in evaluating the data for the experiments from Nos. 21 to 42, which show in some instances an appreciable lowering of the density. The density of tubular specimens of nickel was lower than that of sheet specimens. This is believed to be only partly due to greater experimental difficulties in measuring the density of tubes. Probably the tubes have internal porosities that do not occur in the sheets. It is also possible that the bright nickel tubes may actually contain more impurity than the sheets. The slightly lower densities for the chloride nickel deposits (Nos. 21 to 24) were determined on tubes and may be discounted. The low densities for the Am deposits (Nos. 25 to 28) are probably due to the presence of cracks (see photomicrograph, Fig. 12) and are real. The data for the determinations of the bright nickel sheets (Nos. 31, 36, 38) show that their density is a few parts per thousand lower than that of pure nickel.

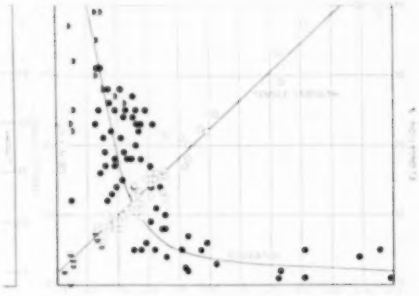


Fig. 19. General relation of hardness to tensile strength and elongation of nickel deposits. Data represent all types of plating solutions and plating conditions, including heat-treated deposits

Clear circles indicate hardness and tensile strength

Dark circles indicate hardness and elongation.

Half-shade circles indicate heat-treated deposits

VII. MECHANICAL PROPERTIES

General

The mechanical properties of nickel deposits, such as hardness, tensile strength, and elongation, are most important for determining the industrial utilization of nickel coatings, e. g., for electroforming or building up worn parts. The assimilation of the large amount of information available concerning the relation of the mechanical properties of nickel to the conditions of deposition is rendered easier by the simple relations which exist between the mechanical properties. Thus, as will be seen, a linear relation exists between hardness and tensile strength and conditions that yield hard deposits also yield deposits of high tensile strength. The relation of elongation to hardness or tensile strength is an inverse one, that is, the harder or stronger a deposit, the lower is its elongation or ductility.

The hardness of nickel has been the subject of more study than any other mechanical property. The literature contains numerous references to the effect of conditions of deposition and of bath composition on the hardness of nickel deposits[16,31,42,58,60,74,97,100,107,112,122,134,135,145] but no comprehensive investigation over a wide range of plating conditions has been published. Of the various theories proposed to explain the relation between the hardness of nickel deposits and the conditions of deposition, some relate hardness to the presence of hydrogen or hydrides in the deposits and others to the presence of inclusions such as basic nickel compounds.

The literature contains relatively few measurements of the tensile strength, elongation, and Young's modulus of electrodeposited nickel[8,47,74,112,126,146,148,160,188,193]. These data deal only with deposits from a few types of solutions under a narrow range of operating conditions. No systematic study of the effects of the plating variables has been made with the exception of two recent papers by Roehl[193,195].

A. Methods of Measurement

1. *Tensile Strength, Elongation, and Young's Modulus of Elasticity*

The test specimens used for measuring these properties were prepared from sheet deposits which were machined to the A. S. T. M. specification E8-46 for thin sheet material, that is, a 2-inch (5 cm) gage length and a 0.5-inch (1.25 cm) reduced width. The cross-sectional areas of the specimens were calculated from measurements of their weight, length, and density. The specimens were tested for ultimate tensile strength in an Amsler testing machine. Some of the bright nickel specimens were so brittle that their

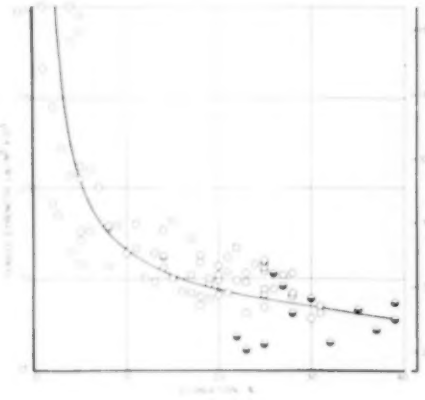


Fig. 20. General relation between tensile strength and elongation of nickel deposits. Data represent deposits from all types of solutions and plating conditions, including heat-treated deposits

Clear circles indicate as-deposited state
Half-shaded circles indicate heat-treated state

ends often broke in the grips of the testing machine and it was necessary to reinforce their ends by the application of a heavy deposit of soft nickel from a Watts bath.

The elongation, which is a measure of the ductility of a deposit, was determined by the increase in length of an initial 2-inch (5 cm) gage length after rupture of the specimen in tension. The results are expressed as a percentage of the initial 2 inches (5 cm). The values of tensile strength and elongation reported in this study in most cases are the averages of measurements on three to six specimens.

Young's modulus of elasticity was determined with Tuckerman optical strain gages, having 2-inch (5 cm) gage lengths and a 0.2-inch (0.5 cm) lozenge. The values of the modulus were calculated from the load and strain values by the method of least squares.

The measurements of tensile strength, elongation, and Young's modulus of elasticity were made by A. Stang and W. B. Campbell of the Mechanical Engineering Section of this Bureau.

2. Hardness

The samples used for the hardness measurements usually consisted of nickel deposited upon a copper tube. A section of the tube was mounted, polished, etched, and repolished prior to testing. The indentations were made on the cross-section of the tube. In some cases the hardness of sheet deposits was measured on their cross-section. The hardness was measured with microhardness testers. In the earlier work a Tukon tester, equipped with a Knoop diamond, was used with a 200-g load. Later an Eberbach hardness tester was used with a Vickers diamond indenter and a load of 250 g. The Knoop numbers were converted to Vickers numbers with the aid of a chart. The hardness values reported represent an average of at least 3 measurements.

The hardness measurements were made by I. C. Minor, S. del Popolo, F. Brodell, and E. Brittin of this Bureau.

3. Reproducibility of Measurements

All precautions were taken in the preparation of deposits to avoid pits and unequal current distribution. Although only macroscopically sound deposits were used in the measurement of the various properties, the results may be influenced by the presence in the deposit of microscopic imperfections and internal stresses. Slight variations in thickness from point to point may also affect certain measurements. In general, the precision of the measurements of the physical constants, such as resistivity, density, and thermal expansivity, was of a higher order than that of the mechanical properties, such as hardness, tensile strength, and elongation, which involve a deformation of the specimen. The elongation was the least reproducible property, probably because it is more sensitive to imperfections in the deposit.

The reliability of the results may be considered from two points of view: (1) the reproducibility of the measurements made on a single specimen or on specimens prepared from a single deposit, and (2) the over-all reproducibility involved in the electrodeposition of the specimens and their measurements. The reproducibility of the measurements was about 5 to 10 per cent for hardness and tensile strength and about 15 to 20 per cent for elongation. The overall reproducibility involved in the electrodeposition of the specimens and the measurement of physical properties was, of course, lower than that in the measurements alone, but it was difficult to determine. The investigators were faced with the dilemma of either collecting a large amount of data with few rechecks, or of collecting a smaller amount of data and rechecking them by the preparation of deposits from an entirely new set of solutions at a later date. A compromise plan was adopted of making a spot check of some of the plating solutions, these being the Watts type, $S_{III}C_I$, the all-chloride type, C, and the all-sulfate solution, S. New baths were prepared and worked for a week or more until the deposits had constant properties, and the hardness and resistivity of the deposits were measured. The comparison of the measurements of hardness, tensile strength, and resistivity of these deposits with similar ones made one to two years previously indicated that the over-all reproducibility of these physical properties was probably of the order of 10 to 20 per cent.

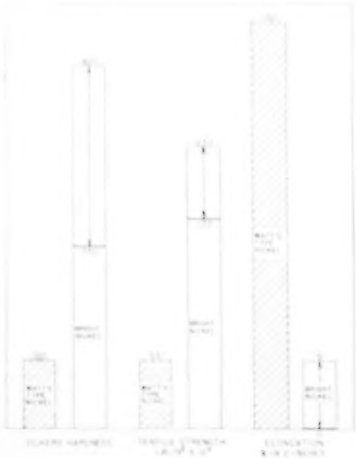


Fig. 21. Comparison of mechanical properties of deposits from Watts type and bright nickel solutions

B. Relation Between Hardness, Tensile Strength, and Elongation

For a given metal an approximately

linear relation usually exists between hardness and tensile strength, and an inverse relation between these properties and elongation. This relation between hardness and tensile strength shows that these two mechanical measurements are dependent upon the same basic physical constants of the material. These general relations between hardness and tensile strength and between hardness and elongation of nickel deposits are shown in Fig. 19 for a number of deposits, including heat-treated specimens. The points representing hardness and tensile strength form a better curve than those representing hardness and elongation, because the overall reproducibility of the property of tensile strength was higher than that of elongation. The inverse relation between tensile strength and elongation is shown in Fig. 20.

The parallel trend between hardness and tensile strength of nickel deposits has been noted previously by several workers, some of whom were aware of the linear relationship[57,74,112,121,122,134,140,180,190].

The relation of hardness to tensile strength or elongation is of considerable practical value because by measuring the hardness of a nickel deposit a reasonable estimate can be obtained of the other two mechanical properties. The measurement of hardness is more rapid, more reproducible, the specimen requires less preparation, and the apparatus is less expensive.

TABLE XII. MECHANICAL PROPERTIES OF NICKEL DEPOSITS FROM THE $S_{III}C_I$, Na, K, AND F SOLUTIONS

Bath	Temp. °C	C.D. amp/dm²	*p*H	Vickers Hardness	Tensile strength lb/in² × 10³	Elongation %
$S_{III}C_I$	55	5	3	150	56	28
Na	55	5	3	147	56	31
K	55	5	3	162		
F	55	5	3	174	62	30

C. Relation Between Mechanical Properties and Conditions of Deposition

1. *Effect of Bath Composition*

The literature contains numerous observations of the effect of bath composition on the hardness of nickel deposits[31,41,48,67,80,74,112,120,121,130,134,144,162,186]. The composition of the plating solution, including special additions to the bath as well as the *p*H, has more effect upon the hardness, tensile strength, and elongation of nickel deposits than have the operating conditions. The mechanical properties of deposits obtained from the different types of plating solutions varied over a wide range. The extremes in mechanical properties are represented by the nickel deposits shown in Fig. 21, which contrasts the hardness, tensile strength, and elongation of the deposit from a Watts-type solution with a bright nickel deposit. The hardness of deposits increases with the type of plating solution in the order: Watts bath, $S_{III}C_I$, 150 DPH*, NH_4, 240 DPH; all chloride, C, and acetate bath, Ac, 285 DPH; bright cobalt nickel bath, f, 400 DPH; ammoniacal nickel bath, Am, 500 DPH; and bright nickel deposits, a, b, c, d, and e, up to 800 DPH. The tensile strength increased in the same order. The photomicrographs in Figs. 11, 12, and 13 show how the fineness of structure parallels the hardness and tensile strength of deposits.

Sodium and potassium ions. Macnaughtan, Gardam and Hammond[66] reported that potassium ions increased the hardness of nickel deposits in the presence of chloride ions and decreased the hardness in the absence of chloride ions. It is also generally believed that the

*DPH, Diamond pyramid number or Vickers' number.

TABLE XIII. MECHANICAL PROPERTIES OF NICKEL DEPOSITS FROM FLUOBORATE SOLUTIONS

	Bath Composition (g/l)			Temp. °C	C.D. amp/dm²	*p*H	Vickers Hardness	Tensile strength lb/in² × 10³	Elongation %	Stress* lb/in² × 10³
	$Ni(BF_4)_2$	Ni	H_3BO_3							
I	232	59	30	55	5	2.0				30
				55	5	2.5	165			
				55	5	3.0	174	62	30	
				55	5	3.5	172			
				55	5	4.5	169	69	22	
				20	5	3.0	252			
II	300	75	30	54	3.2	2.6	128	56	32	
					5.4					15
III	440	110	30	54	8.1	2.0	164	55	20	
	440	110	41	43	10.7	3.5				24
	300	75	30	54	8.1	2.5	183	74	17	
	300	75	30	54	8.1	3.5	159	69	13	
	220	55	30	32	5.4	3.5	243	100	14	
	220	55	30	43	10.7	3.0				24

*Stress refers to a deposit thickness of 0.001 inch.

I—NBS results.

II—E. J. Roehl and A. W. Wesley, Plating 37, 142 (1950).

III—C. Struyk and A. E. Carlson, Plating 37, 1242 (1950).

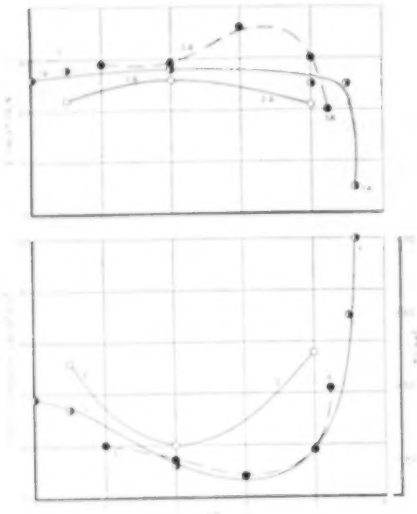


Fig. 22. Effect of pH of plating bath on tensile strength and elongation of nickel deposited at 2 and 5 amp dm² (19 and 46 amp ft²)

Curve 1—$S_{III}C_1$ at 55° C (131° F)

Curve 2—$S_{III}C_1$, $oS_{III}C_1$, and Na baths at 30° C (86° F) and 55° C (131° F)

Curve 3—composite of data from Gardam and Macnaughtan[12] and Roehl[89, 139]

presence of sodium ions affects the mechanical properties of nickel deposits, although no detailed studies are found in the literature. High concentrations of sodium sulfate were used at one time in solutions for nickel plating zinc base die castings and the deposits were more brittle, had a higher tensile strength, and, by implication, a higher hardness than ordinary Watts-type nickel[205]. The marked difference of these deposits, however, might be due as much to the higher viscosity of the solution as to the presence of the sodium ion itself.

In the present investigations, solutions Na and K each contained a relatively low concentration (0.5N) of sodium or potassium sulfate (Na_2SO_4, 36 g/l or 5 oz/gal; K_2SO_4, 44 g/l or 6 oz/gal). The properties of deposits from these solutions were, within the experimental error, similar to those from the corresponding $S_{III}C_1$ solution. In view of this similarity it is unnecessary to discuss the Na and K solutions separately with respect to any of the physical properties and for practical purposes they may be considered the same as the $S_{III}C_1$ solution (see Table XII). This result is not in agreement with the findings of the British authors cited above[205].

Fluoborate ions. The physical properties of deposits from the fluoborate bath are also very similar to those from the $S_{III}C_1$ solution, as shown in Table XII. Considerable interest has developed in recent years in deposits from fluoborate solutions and in the physical properties of these deposits[193-201]. Table XIII gives the data for deposits from our fluoborate bath, F, and permits a comparison between our values and those published by other investigators. The agreement is satisfactory as evidenced by the table.

Ammonium ions. The hardening effect of ammonium salts when present in a Watts-type solution has been the subject of special study[31, 48, 87, 89, 112, 131, 138] and has led to the use of ammonium salts in the so-called "hard nickel" baths. The hardening effect of ammonium salts is most noticeable in the high *pH* range,

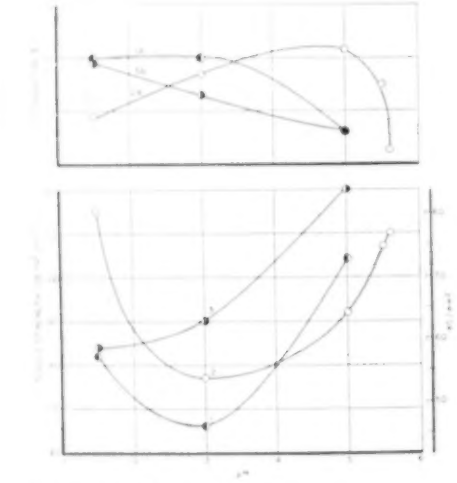


Fig. 23. Effect of pH of plating bath on tensile strength and elongation of nickel deposited at 5 amp dm² (46 amp ft²). Curves marked with an A represent elongation, the others tensile strength

Curve 1—S bath at 55° C (131° F)

Curve 2—NH_4 at 55° C (131° F)

Curve 3—C, S_1C_1, S_1C_{III} at 30° C (86° F) and 55° C (131° F) and 80° C (176° F)

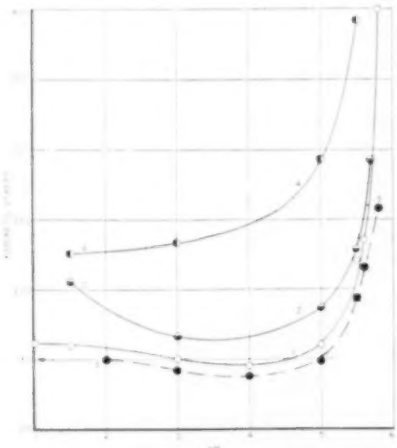


Fig. 24. Effect of pH of plating solutions on hardness of nickel deposits

Curve 1—$S_{III}C_1$ bath at 55° C (131° F) and 5 amp dm² (46 amp ft²)

Curve 2—$S_{III}C_1$, Na, NH_4 baths at various temperatures and current densities

Curve 3—composite data from Macnaughtan and Hammond[88], Macnaughtan, Gardam, and Hammond[89], and Roehl[139]

Curve 4—S_1C_1, S_1C_{III}, C, and oC baths at 55° C (131° F) and 5 amp dm² (46 amp/ft²)

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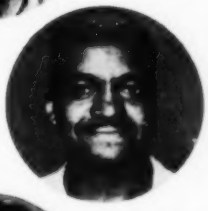

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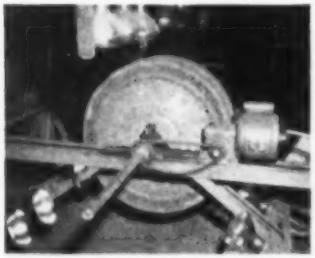
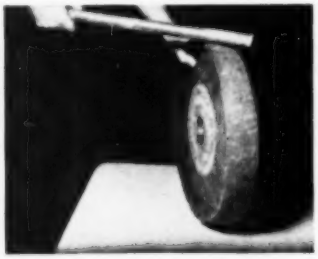
HOW TO SET UP a polishing wheel. Glued wheel, shown here, is automatically rolled in a trough of abrasive grain. To minimize jelling, the setting-up operation is carried out as quickly as possible.



HOW TO DRY a polishing wheel. Infrared lamps dry wheels faster and permit smaller inventory of wheels. Note mechanism for rotating wheels easily. Ideal dry room maintains temperature of 85° F. and 50% relative humidity. When wheel cracks readily, it is dry.



HOW TO CRACK the wheel head. Wheel face is hit at about a 45° angle, being struck completely around the wheel once or twice. It is then hit at an angle that forms an "X" with the first series of cracks. A round bar or pipe, *not a sharp tool*, is used.

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for example, at a *p*H of 5.0 or above.

Organic compounds. The hardening effect of organic additions to a nickel plating solution is well known and has received some study[87, 90, 100, 112, 120, 162, 198]. Our data show that the organic additions produced the hardest nickel deposits, some of which were about as hard as electrodeposited chromium.

2. *Effect of pH*

In its influence on the mechanical properties of nicked deposits, the *p*H of the plating solution is second in importance only to the nature of the bath constituents. In general, the mechanical properties of deposits produced in the *p*H range from 1–5 show only minor variations, that is, the values of physical properties with increasing *p*H up to 5 may rise or fall slightly, or there may be a slight minimum or maximum. If the *p*H of the solution is made high enough there is a marked increase in the hardness and tensile strength of the deposit and a decrease in elongation. In practice one can not take advantage of these extreme properties at the high *p*H because along with the increase in strength there occurs such a great increase in stress that the deposits are likely to crack spontaneously or exfoliate. Because of this difficulty, tests could not be made on deposits plated at high *p*H from many of the solutions, but, in examining the graphs, it should be realized that had such measurements been possible the curves would have shown a steep branch in the high *p*H range.

Figs. 22, 23, and 24 show the variation with *p*H of the mechanical properties of deposits obtained from the S and the $S_{III}C_I$ baths at 55° C and 5 amp/dm² (curve 1) and of those obtained from other Watts-type baths over a range of conditions (curve 2). The curves marked "A" indicate the data on elongation that correspond to the similarly numbered curves for tensile strength. At a *p*H of about 3 to 4 these three pairs of curves (1 and 2 in Figs. 22, 23, and 24) show a minimum for hardness and tensile strength, and the corresponding "A" curves show a maximum for elongation. Although the minima and maxima shown by these curves are not very pronounced, they probably are real since the three mechanical measurements, hardness, tensile strength, and elongation, yielded corresponding results. The deposits from the Watts bath, $S_{III}C_I$, represented by curve 1 in Figs. 22 and 24, at a *p*H of 3 to 4 are outstanding among nickel deposits in having the lowest hardness and tensile strength and the highest elongation.

Minima in hardness and tensile strength have been reported previously in the literature. Curve 3 in Fig. 22 is a composite of the data of Gardam and Macnaughtan[87] and Roehl[88, 199] for deposits obtained from a plating solution similar

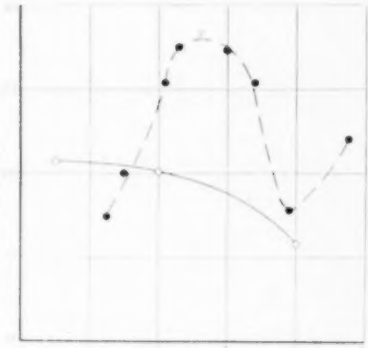


Fig. 25. Effect of pH of plating bath on hardness of nickel deposits

Curve 1—S bath at 55° C (131° F) and 5 amp/dm² (46 amp/ft²)
Curve 2—N.S.B. bath of Macnaughtan, Gardam and Hammond[6].
Composition similar to our S bath

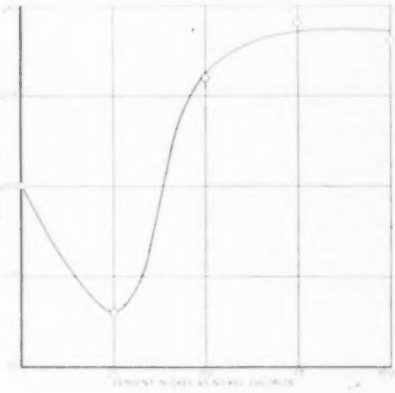


Fig. 26. Effect of chloride content of plating bath on hardness of nickel deposits. Each point represents the average hardness of 5 to 10 deposits each produced under different conditions of plating

Temperature range: 30° to 80° C (86° to 176° F)
Current density range: 2 to 5 amp/dm² (19 to 46 amp/ft²)
pH range: 1.5 to 5.0

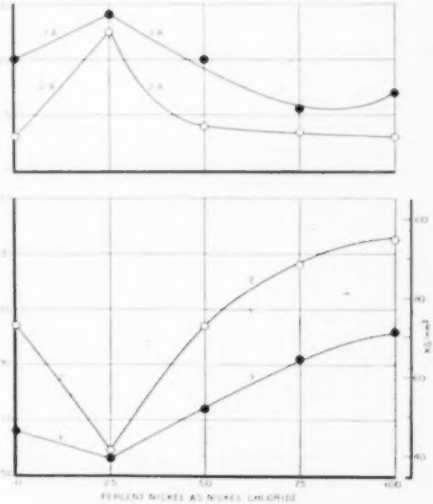


Fig. 27. Effect of chloride content of plating bath on tensile strength and elongation of nickel deposited at 55° C (131° F) and 5 amp/dm² (46 amp/ft²). Curves marked with an A represent elongation, the others tensile strength

Curve 1—S, $S_{III}C_I$, S_IC_I, S_IC_{III}, and C baths at pH 3.0
Curve 2—Same baths at pH 5.0

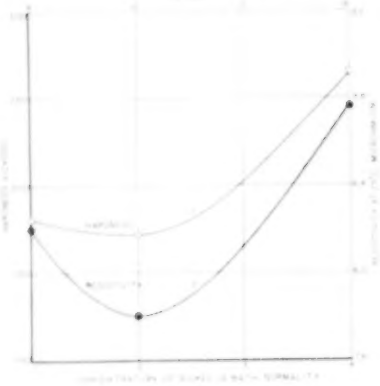


Fig. 28. Effect of nickel content of plating bath on hardness and resistivity of nickel deposited from the $S_{III}C_1$ (−1N), $S_{III}C_1$, and $S_{III}C_2$ (−4N) baths

Curve 1, hardness—each point is the average hardness of 6 deposits each produced under different plating conditions

Curve 2, resistivity—each point is the average resistivity of 5 deposits each produced under different plating conditions

to our $S_{III}C_1$ but under slightly different operating conditions. The agreement with curve 1 is quite satisfactory. Similarly, curve 3 in Fig. 24 is a composite of the data of Roehl[98], Macnaughtan and Hammond[99], and Macnaughtan, Gardam, and Hammond[97] on the hardness of nickel deposited from solutions similar to our $S_{III}C_1$ bath. Here, also, the agreement with curve 1 is satisfactory.

Some deposits did not show a minimum hardness or tensile strength at a *p*H of 3. Curve 4 in Fig. 24 and curve 3 in Fig. 23 are averages that represent the hardness and tensile strength, respectively, of deposits from plating solutions containing relatively large concentrations of chloride. These curves show a steady trend toward higher values of hardness and tensile strength as the *p*H is increased.

The only deviation from the usual parallel trend of hardness and tensile strength with *p*H is shown by curve 1 in Figs. 25 and 23, which represent the data for the all-sulfate solution, S. The tensile strength curve (Fig. 23) shows the usual minimum, but the curve for hardness (Fig. 25) shows a steady decrease in hardness with increase of *p*H. If the observations on hardness had been carried to a still higher *p*H, the curve would no doubt have started to rise sharply to the right. Curve 1, Fig. 25, does not agree very well with curve 2, which represents the data of Macnaughtan, Gardam, and Hammond[99] for deposits obtained from a solution similar to our S bath. The curves approach each other at a *p*H of 2.5 and 5, but the maximum in hardness obtained by the other workers was not duplicated, and evidence of such a maximum was not obtained with any other type of plating solution.

The hardening effect of a high *p*H upon nickel deposits has been observed and commented on frequently[98,19,31,80,77,112,120,134,140,148]. Macnaughtan and Hothersall[31] attributed it to the increased codeposition of basic material. This theory is a special case of a general hypothesis on the effect of impurities on the properties of deposits, which will be discussed later. Macnaughtan and Hothersall did not analyze their nickel deposits, but depended upon microscopic examination of heat-treated deposits to estimate the content of oxide. The effect of *p*H on the oxide content of deposits has already been discussed. Comparison of Fig. 5 with Figs. 22 and 24 shows the parallelism between the increase of oxide content and the increase of tensile strength and hardness.

The changes in the structure of nickel deposits with *p*H parallel the variations in the mechanical properties of the deposits. The photographs in Fig. 9 show that a much finer-grained structure occurs at a high *p*H, at which harder, stronger deposits are produced. However, the minima found in hardness and tensile strength at a *p*H of 3 are not accompanied by any noticeable change in the structure.

3. *Effect of Chloride Content*

The chloride content of a nickel plating solution is an important factor in determining the physical properties of the deposits. It is well known that the addition of chloride will increase the hardness[98,80,74,121,133,134,149,142,146,148] and the tensile strength but will reduce the ductility of nickel deposits. However, no comprehensive, systematic study has been made.

The curve in Fig. 26 represents the average of the hardness data as a function of the chloride content for deposits from 5 baths and 35 plating conditions. The curves in Fig. 27 show the variation of tensile strength and elongation with chloride content at two different *p*H values. The most interesting feature of Figs. 26 and 27 is that both the hardness and tensile strength show a pronounced minimum and the elongation a maximum at a chloride content corresponding to the $S_{III}C_1$ solution. A further increase in chloride content of the bath results in a considerable increase in the hardness and tensile strength of the deposits. Fig. 27 shows also the effect of *p*H in increasing the tensile strength. The structures of the deposits (Fig. 10) show that the grain size decreases with increasing chloride content, with the exception that the minimum in hardness and tensile strength that results from converting the S bath into the $S_{III}C_1$ bath is not reflected by changes in structure. (that is the S and

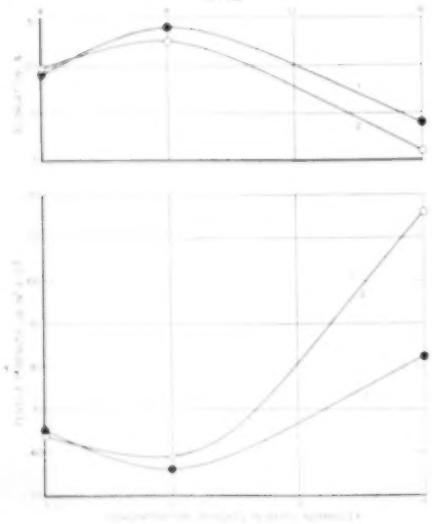


Fig. 29. Effect of nickel content of plating bath on tensile strength and elongation of nickel deposited at 55° C (131° F) and 5 amp/dm² (46 amp/ft²). Curves marked with an A represent elongation, the others tensile strength

Curve 1—$S_{III}C_1$ (−1N), $S_{III}C_1$, and $S_{III}C_2$ (−4N) baths at pH 3.0

Curve 2—same baths at pH 5.0

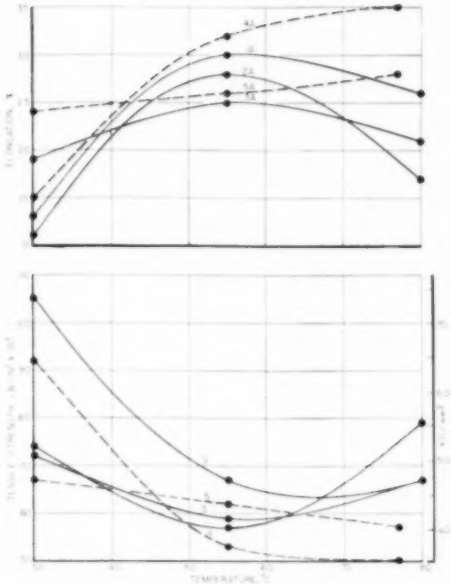


Fig. 30. Effect of temperature of plating bath on tensile strength and elongation of nickel deposited at 5 amp/dm² (46 amp/ft²). Curves marked with an A represent elongation, the others tensile strength

Curve 1—$S_{III}C_l$, o$S_{III}C_l$, and Na baths at pH of 3.0
Curve 2—$S_{III}C_l$ bath at pH of 1.5
Curve 3—$S_{III}C_l$ bath at pH of 5.0
Curve 4—Watts bath (Roehl[39]) at pH of 2.0
Curve 5—Watts bath (Roehl[39]) at pH of 5.0

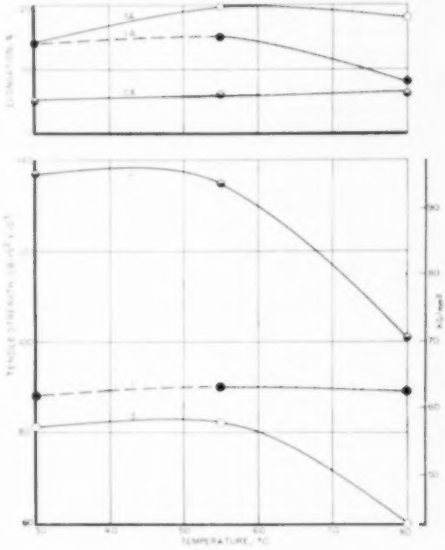


Fig. 31. Effect of temperature of plating bath on tensile strength and elongation of nickel deposited at 5 amp/dm² (46 amp/ft²). Curves marked with an A represent elongation, the others tensile strength

Curve 1—C, S_lC_l, S_lC_{III} baths at pH 1.5 to 3.0
Note: the value at 30° C is a single value for the C bath, curve 1
Curve 2—C bath at pH of 5.0
Curve 3—S bath at pH of 1.5

the $S_{III}C_l$ deposits have about the same grain size).

Electroplaters and electrotypers have long known that addition of some chloride to a sulfate nickel bath yielded softer deposits. Hothersall[16] pointed out the existence of a minimum in the hardness and tensile strength of nickel deposits at a certain chloride content. Macnaughtan, Gardam, and Hammond[40] concluded from their investigations that addition of chloride to a low *p*H bath caused a softening of nickel deposits. This observation is in agreement with ours, since their baths contained a relatively low concentration of chloride, which would correspond to compositions to the left of our minimum point.

4. Effect of Nickel Content

The concentration of nickel in the plating solutions has a minor effect on the physical properties of nickel deposits. The curves in Fig. 28 depict the average of the data for 6 different operating conditions. Fig. 29 shows data for solutions operated at two different *p*H values. As shown in these figures there is no appreciable difference in the hardness, tensile strength, and elongation of deposits obtained from $S_{III}C_l$ solutions that are 1*N* and 2*N* in nickel (which is the range of concentration commonly used for plating). These observations agree with those of other workers[16, 28, 31, 33]. However, the deposits obtained from 4*N* solutions show a considerably greater hardness and tensile strength and a lower elongation than deposits from 2*N* plating solutions. Data for deposits from the 4*N* all-chloride solution, C (not shown in the figure),

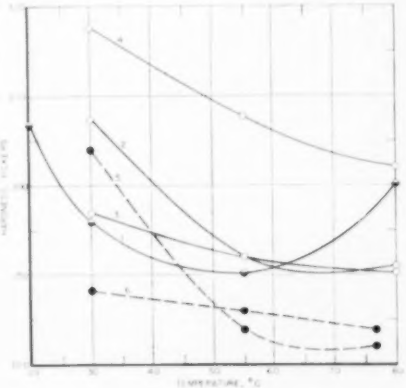


Fig. 32. Effect of temperature of plating bath on hardness of nickel deposited at 5 amp/dm² (46 amp/ft²)

*Curve 1—$S_{III}C_l$, o$S_{III}C_l$, $S_{III}C_l$ (−1*N*), and Na baths at pH 3.0*
Curve 2—$S_{III}C_l$ bath at pH 1.5
Curve 3—$S_{III}C_l$ bath at pH 5.0
*Curve 4—$S_{III}C_l$ (−4*N*), NH_4, S_lC_l, S_lC_{III}, and C baths at pH 1.5 to 5.0*
Curve 5—Watts bath (Roehl[39]) at pH 2.0
Curve 6—Watts bath (Roehl[39]) at pH 5.0

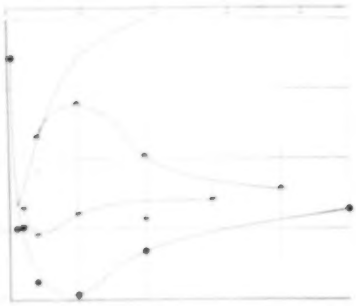


Fig. 33. Effect of current density on hardness of nickel deposited at 55° C (131° F)

Curve 1—C bath at pH 5.0
Curve 2—$S_{III}C_I$ (~4N) bath at pH 5.0
Curve 3—S_IC_I bath at pH 3.0
Curve 4—$S_{III}C_I$, $aS_{III}C_I$ baths at pH 1.5 to 5.0

shows that these deposits also are harder than those from the corresponding 2N solution.

The influence of bath composition upon the mechanical properties of nickel electrodeposits has not been satisfactorily explained. For the present the adsorption theory[37] may serve as a working hypothesis. The material adsorbed from the bath by the growing deposit may function in two ways to increase hardness and tensile strength of nickel deposits: (1) by interfering with the growth of large crystals it produces a finer-grained structure, which has the higher hardness and tensile strength usually associated with fine-grained structures; and (2) the adsorbed impurities are finely dispersed throughout the deposit in a submicroscopic condition and may increase the hardness and tensile strength in the manner ascribed to precipitation hardening.

5. *Effect of Operating Conditions*

Temperature and current density have relatively less effect upon the mechanical properties of nickel deposits than has the composition of the plating solution. The effect of an operating condition on a property depends upon the other conditions of deposition, and the parallelism between variations in hardness and in tensile strength is not as pronounced as in the examples cited in the discussions of solution composition.

Temperature. The effect of temperature of the plating solution on the hardness has been studied[9,28,31,38,39,43], but relatively little work has been done with regard to tensile strength. Figs. 30 and 31 show the variations of tensile strength and elongation, and Fig. 32, the variation of hardness with the temperature of the plating bath. Curves closely situated were averaged and represented as a single curve. One of the familiar aspects of the data is that the deposits obtained at a temperature of 55° C from the Watts solution, $S_{III}C_I$, at a *p*H of 3 show a minimum hardness (curve 1, Fig. 32) and a minimum tensile strength (curve 1, Fig. 30). A minimum hardness of deposits formed at intermediate temperatures has been observed previously[39]. The grain structure of these deposits parallels the hardness and tensile strength, as the deposit obtained at 55° C (Figs. 7E and 7H) has a coarser structure (corresponding to the minimum of tensile strength and hardness) than the deposits produced at a lower temperature (Figs. 7A and 7B) or at 80° C (Figs. 7F and 7I).

The apparent minimum in tensile strength at about 55° C shown by deposits from the Watts bath at a *p*H of 3 (curve 3, Fig. 30) is probably not real, as the corresponding curve for hardness (curve 3, Fig. 32) does not show a minimum. The apparent decrease in tensile strength at 55° C is about equal to the experimental error.

With the exception of the minima just noted, the main trend is a decrease in tensile strength and hardness with increase in temperature (curve 2, Fig. 30; curves 2 and 3, Fig. 31; and curves 2, 3, and 4, Fig. 32). The dotted curves in Figs. 30 and 32 show data obtained by Roehl[38] for deposits from a Watts solution. In Fig. 30 his curve 4 is to be compared with our curve 2, which represents deposits obtained at a *p*H of about 2, while his curve 5 is to be compared with our curve 3, which represents deposits obtained at a *p*H of 5. In Fig. 32 the corresponding curves to be compared with respect to hardness are curve 5 (Roehl) with our curve 2; and curve 6 (Roehl) with our curve 3. The agreement of Roehl's data with ours is qualitatively satisfactory. In the case of these deposits the microstructure parallels again the trend of mechanical properties. Compare, for instance, pictures A, B and C in Fig. 7a with curve 3 in Figs. 30 and 32 or pictures D, E and F in Fig. 7a with curve 2 in Figs. 30 and 32. Also pictures G and H in Fig. 7a are to be compared with the composite curve 4 in Fig. 32.

The properties of deposits from the S bath did not vary in a consistent manner with temperature changes. In Fig. 31 curve 3 shows that the tensile strength decreased with an increase in temperature of deposition. On the other hand, the hardness of deposits obtained under these same conditions increased with temperature (curve not shown). These discrepancies are probably the result of the greater difficulty involved in obtaining reproducible deposits from the all-sulfate plating solution.

The variation of elongation of the deposits with temperature of deposition is relatively small (Figs. 30 and 31). It is more difficult to establish even a trend because of the lower reproducibility of these measurements. In general, the elongation of Watts-type deposits plated at 80° C is slightly greater than that of deposits plated at 30° C (Fig. 30), and this increase in elongation is parallel to the decrease in tensile strength. The slightly higher elongations at 55° as compared with 80° C are within experimental error and may not be real. Fig. 31 shows that the elongation of the deposits from the solutions high in chloride is not very much affected by temperature and does not parallel the decrease in hardness of the deposits. The data of Roehl on the elongation of deposits, shown by the dotted lines in Fig. 30, are in good agreement.

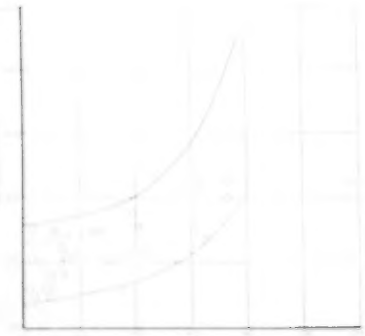


Fig. 34. General relation between hardness and oxygen content of nickel deposited from all solutions under various plating conditions

TABLE XIV. YOUNG'S MODULUS OF ELASTICITY OF NICKEL DEPOSITS FROM VARIOUS SOLUTIONS

Expt. No.	Bath	Temp. °C	C.D. amp/dm²	pH	Velocity of sound		Modulus of elasticity calculated		Modulus of elasticity measured		Difference between measurement and calculation	
					ft/sec	meter/sec	lb/in² × 10⁶	kg/mm² × 10³	lb/in² × 10⁶	kg/mm² × 10³	lb/in² × 10⁶	kg/mm² × 10³
1	S	55	5	3	15,051	4587	27.3	19.1	23.5	16.5	3.8	2.6
2		55	5	5					23.0	16.1		
3	oS	55	5	1.5					25.5	17.9		
4	$S_{III}C_I$	10	2	3	14,691	4477	26.0	18.2				
5		30	5	3	15,843	4829	30.3	21.2	23.8	16.6	6.5	4.6
6		55	1	3					23.6	16.5		
7	"	55	1	3					24.7	17.3		
8		55	5	1					26.3	18.4		
9		55	5	3	16,077	4900	31.2	21.8	24.1	16.9	7.1	4.9
10		55	5	5					23.7	16.6		
11		80	5	3					27.3	19.1		
12	$oS_{III}C_I$	55	5	3	15,300	4663	28.2	19.7	22.3	15.6	5.9	4.1
13		55	5	5					28.4	19.9		
14	$S_{III}C_I$+1N	55	5	5					19.7	13.8		
15	$S_{III}C_I$+4N	55	5	5					27.2	19.0		
16	S_IC_I	55	5	3	14,677	4473	26.1	18.3	25.1	17.6	1.0	0.7
17		55	5	5					28.2	19.7		
18	S_IC_{III}	55	5	3	15,317	4668	28.3	19.8	26.8	18.8	1.5	1.0
19	C	55	5	3					30.8	21.6		
20		55	5	5	14,834	4521	26.5	18.6	28.6	20.0	2.1	1.4
21	oC	55	5	3	15,909	4849	30.5	21.4				
22	Na	55	5	3	15,863	4835	30.3	21.2	24.1	16.9	6.2	4.3
23	NH_4	55	5	3					25.3	17.7		
24		80	5	5					26.4	18.5		
25		55	5	5.7	15,274	4655	28.2	19.7	24.0	16.8	4.2	2.9
26	"	55	5	5.7			28.2	19.7	25.0	17.5	3.2	2.2
27	Ac	50	5	4.5	15,902	4847	30.5	21.4	22.8	15.9	7.7	5.5
28	F	55	5	3					20.4	14.3		
29	a		6	...					24.7	17.3		
30	b		6	...					23.4	16.4		
31	c		2	...					22.4	15.7		
32	d		4	...					24.4	17.1		
33	f	65	5	3.7	15,867	4836	30.5	21.4	25.8	18.1	4.7	3.3

*Prestressed—a second specimen of the same material was prestressed within the elastic range to eliminate any effects of residual internal stress before the measurement of the modulus was made. The difference between the as-deposited specimen and the prestressed specimen is not significant.

Current density. It is commonly believed that an increase in current density increases the hardness and tensile strength of nickel deposits. Observations on the subject have been made by a number of workers[10,26,74,110,162,330] but no systematic study has been reported. Our data show no pronounced trend of hardness with current density within the ordinary plating ranges, but there is some evidence that at very low current densities, e.g., 0.25 amp/dm² (2 amp/ft²), or very high current densities, e.g., above 25 amp/dm² (233 amp/ft²), the hardness of the deposits increases.

The curves in Fig. 33 show the variations obtained with different types of solutions. The variations in curves 2 and 3 may well be within the experimental error. Curve 4, which is a composite for several different conditions of plating from the $S_{III}C_I$ bath, shows very little variation with current density except at the lowest current densities. The increased hardness at the lowest current density is consistent with the photomicrographs in Fig. 8, which show that these deposits have a much finer-grained structure than those obtained at higher current densities. Curve 1, for the all-chloride bath at a relatively high *p*H, is exceptional in that it shows a large increase in hardness with current density. Curves for the Ac and S solutions were erratic and are not reproduced here.

The data on the effect of current density on the tensile strength and elongation were not complete enough to warrant any conclusions. Roehl[330] found no appreciable change in hardness, tensile strength, or elongation of deposits produced in the range of 1.1 to 5.5 amp/dm² (10 to 50 amp/ft²) from a solution similar to $S_{III}C_I$ at a *p*H of 3, and found a decrease in hardness and tensile strength, but no change in elongation for deposits obtained at a *p*H of 5. Blum and Kasper[74] found that the tensile strength of deposits obtained from a plating solution near the boiling point increased about 15 per cent when the current density was increased from 22 to 42 amp/dm² (205–390 amp/ft²).

D. Relation Between Mechanical Properties and Composition of Deposits

Most nickel deposits contain several tenths of a per cent of cobalt, which is present as an impurity in the salts and anodes manufactured in this country. A comparison of the properties of nickel deposits obtained from the cobalt-containing solutions with the deposits from the

TABLE XV. ENDURANCE LIMIT, ENDURANCE RATIO, TENSILE STRENGTH, ELONGATION, AND YOUNG'S MODULUS OF NICKEL DEPOSITS

Expt. No.	Bath	Temp. °C	C.D. amp/dm²	pH	Tensile strength lb/in² × 10³	Tensile strength kg/mm²	Elong. %	Young's modulus lb/in² × 10³ (measured)	Young's modulus kg/mm² × 10³ (measured)	Endurance limit for 10⁷ cycles lb/in² × 10³	Endurance limit for 10⁷ cycles kg/mm²	Endurance ratio
1	$S_{III}C_I$	30	5	3	75	53	15	23.8	16.6	a. 36	25	0.480
										b. 44	31	
2	$S_{III}C_I$	55	5	3	56	39	28	24.1	16.9	a. 30	21	0.535
										b. 37.5	26.3	
3	$S_{III}C_I$	55	5	5	59	41	25	23.7	16.6	35	24.5	0.593
4	C	55	5	5	135	95	6	28.6	20.0	a. 40	28	0.296
										b. 60	42	
5	Ac	50	5	4.5	147	103	4	22.8	16.0	80	56	0.544
6	S_IC_{III}	55	5	3	92	64	11	26.8	18.8	a. 40	28	0.434
										b. 50	35	
7	e		2		196	137	3	22.4	15.7	101	71	0.515
8	e		1.7		232	162	3	24.5*	17.2*	110	77	0.474
9	f	65	5	3.7	206	144	4	25.8	18.1	116	81	0.564
10	ORT	55	2	3.5	170	119	2	24.5*	17.2*	98	67	0.576
										average		0.501
	commercial sheet nickel 0.02 inch thick (98)				72	50	40	22.6	15.8	for 10⁵ cycles 25	18	0.347
					113.5	79	2	27.0	18.9	39.5	27.6	0.348
					121.5	85	2	30.3	21.2	40.5	28.4	0.333

a—Rough surface.
b—Smooth surface.
*Assumed value of modulus.

corresponding cobalt-free solutions showed that within the precision of the measurements there is no difference in mechanical properties (Table III). The exceptional physical properties of the deposits from the "f" solution are to be attributed to the effect of organic addition agents in the plating solution rather than to the presence of about 1 per cent of cobalt in the deposits.

One of the earliest theories attributed the exceptional physical properties of electrodeposited nickel to the presence of codeposited hydrogen. After thorough investigations by various workers[28,31,32,33] this theory was discredited, as it was demonstrated that most of the hydrogen could be removed from nickel deposits by annealing at a temperature of about 400° C without materially lowering the hardness of the deposit. Kremann[34] was one of the first to question the role of hydrogen and believed the structure of the deposit to be responsible for the unusual hardness of electrodeposited nickel. Macnaughtan and coworkers[27,77] advanced the theory that the variations in the hardness of electrodeposited nickel result from the presence of codeposited colloidal basic nickel compounds. Similar ideas had been suggested previously[28,42], but Macnaughtan and coworkers were the first to offer concrete experimental evidence by making a microscopic examination of heat-treated deposits to reveal the presence of agglomerated oxides. However, our experience with the microstructure of annealed deposits (see Figs. 58 to 62) indicates that this procedure could not be used for estimating the actual amount of oxide present.

In the present work a correlation between the oxygen content and the mechanical properties of nickel deposits was found to exist when only a limited number of variables was involved in the deposition. Thus, when the *p*H was the only variable, a good correlation existed between the oxygen content of the deposits and the tensile strength and hardness, as can be seen by comparing Fig. 5 with Figs. 22 and 24. Similarly, when current density was the only variable, a good correlation existed between the oxygen content of the deposits and the hardness, as can be seen by comparing Fig. 4 with curve 4 of Fig. 33. However, if deposits obtained from all types of solutions under all conditions of plating are considered, a relation between the mechanical properties of the deposits and the oxygen content is not so apparent. In

Fig. 35. Variation of Young's modulus of elasticity with chloride content of plating bath. Each point is an average for deposits produced from the S, $S_{III}C_I$, S_IC_I, S_IC_{III}, and C baths at a temperature of 55° C (131° F), 5 amp/dm² (46 amp/ft²), and a pH of 3.0 and 5.0.

Fig. 34 the hardness of a number of deposits has been plotted against the oxygen content. There is a definite trend toward higher hardness with increasing oxygen content of the deposit. The figure shows that deposits containing less than 0.04 per cent oxygen are softer than 270 Vickers, and deposits with greater oxygen contents have a higher hardness. However, small amounts of other inclusions, e. g., chloride, may also influence the mechanical properties of the deposits and mask the effect of oxygen. Furthermore, the effect of a given content of impurities in the deposit may depend upon secondary factors that cannot be evaluated, (for example, the particle size and distribution of the inclusions, and the effect of the inclusions upon the refinement of the grain structure of the deposit).

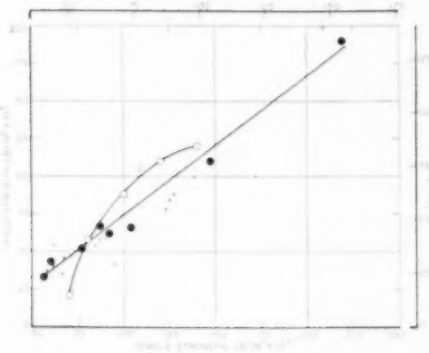


Fig. 36. Relation between yield strength and tensile strength in nickel deposits

Curve 1 represents deposits obtained from 8 different baths

Curve 2 represents data on commercial nickel[135,166]

Crosses represent unpublished data for electrodeposited nickel, privately communicated[150]

E. Young's Modulus of Elasticity

The modulus of elasticity of a metal does not vary with the conditions of the metal as much as do the other mechanical properties. For example, the modulus of a piece of hardened steel differs very little from the modulus of very soft annealed steel. Therefore, it was rather surprising to find a considerable variation in the modulus of electrodeposited nickel according to the conditions of deposition. The modulus of commercial metallurgical nickel is about 30×10^6 lb/in^2 (21×10^4 kg/mm^2)[97,137]. No references to the modulus of electrolytic nickel were found in the literature. As shown in Table XIV, the moduli of some of our deposits were as low as 20×10^6 lb/in^2 (14×10^4 kg/mm^2). Prestressing of the deposits before measuring the modulus did not result in any appreciable difference in the value. The moduli of several specimens were checked in the laboratory of the International Nickel Company by W. A. Wesley, with results close to our values.

As the large deviation from the accepted value of the modulus shown by some deposits was not easy to explain, it was considered desirable to check some of the values by an independent method. The velocity of sound in some of our deposits was measured by H. L. Fusfeld of Frankford Arsenal. The modulus of elasticity was calculated from the velocity of sound by the following formula: $E = V^2 \times d$, where E is Young's modulus of elasticity, V is the velocity of sound in the metal, and d is the density (taken as 8.90 g/cm^3). The values of the modulus calculated on this basis are given in Table XIV. With one exception they are higher than the more directly measured values, and some of them are close to the accepted value. Dynamic methods of measuring modulus always yield higher values than static methods[138]. However, the calculated values may be more nearly correct than the measured ones, because imperfections, discontinuities, and thickness variations probably have a greater effect on the direct method of measurement.

No systematic study was made of the relation between the modulus of the deposits and the conditions of deposition, but data were obtained on the effect of the chloride content. Fig. 35 shows that the modulus of the deposit increases with the chloride content of the plating solutions. However, if the moduli, calculated from the velocity of sound, are similarly plotted against chloride content of the plating solution, no such trend can be seen.

F. Fatigue Limit

The fatigue or endurance limit is a measure of the ability of a metal to resist fracture under repeated stress and is therefore of interest in the application of metals to structures subject to vibration, such as machinery and airplanes. It is defined as the limiting stress below which a metal may be subjected to an indefinite number of stress cycles without fracture. The fatigue limit shows an approximate relation to tensile strength, and a still rougher relation to yield strength and ductility. The ratio of the fatigue limit to the tensile strength is called the endurance ratio, which for nonferrous metals may vary from 0.15 to 0.4; that is to say, the fatigue limit of a metal may be from 15 per cent to 40 per cent of its tensile strength. The fatigue limit is more affected by imperfections or inhomogeneities in the metal than are other mechanical properties. Variations in thickness of the specimen, the presence of holes or pores, the existence of stress, and the nature of the surface will affect the measurements.

A knowledge of the fatigue limit of electrodeposited nickel may be of interest in connection with the use of nickel (1) as a coating on a basis metal such as steel, and (2) as an electroformed material. In this study the fatigue limit of electroformed nickel sheets only was determined. No references were found to determinations of the fatigue limit of electrodeposited nickel, although there were numerous references to wrought or cast nickel.

The strength of the nickel deposits in fatigue was determined by subjecting them to a large number of cycles of stress in a fatigue testing machine for thin sheet specimens which was designed by the Metallurgy Division of this Bureau, using the fundamental features of a Krouse testing machine*. Rectangular specimens, 2.5 x 1.3 cm (1 inch x $\frac{1}{2}$ inch), were cut from the electrodeposited sheets. Their ends were made accurately parallel by filing, and the long edges were smoothed with abrasive paper. In the cutting of the specimens, an effort was made to avoid any surface irregularities near the middle, but this was not always possible;

*This machine has been described in Nat. Bur. Standards, Tech. News Bull., Vol. 35, No. 7 (1951).

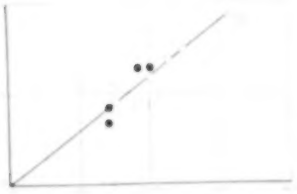


Fig. 37. Relation between internal friction and hardness of nickel deposits. Data from Table XVI

hence, some of the scatter of the results may be caused by the concentration of stress around local imperfections. Of the other factors which tended to reduce the precision of the results, the most important was variation in thickness of the specimen. Some specimens varied 0.0025 cm (0.001 inch) in thickness from one edge to the other, and, since the sheets were on an average only 0.025 cm (0.01 inch) thick, these variations were important in terms of the calculated maximum stress. The specimens were stressed by bending in one direction only from the flat position so that during the bending one side of the strip was always under tension and the other under compression. The measurements were made by J. A. Bennett of this Bureau.

No difficulty was experienced in determining the fatigue limit of bright nickel deposits, but the testing of dull nickel deposits was subject to uncertainty, since the deposits could not be broken by repeated stress unless the stress was large enough at the beginning of the test to deform the nickel plastically. This means that the dull nickel deposits were stressed in the machine with an amplitude so large that they did not regain their initial equilibrium shape. The specimens were then straightened. This operation introduced enough cold work in the specimens so that they recovered elastically from each bend in the subsequent testing. The nickel, as eventually tested, thus differed from the original deposit in having a certain amount of cold work or internal stress. Because this degree of cold work could not be duplicated with each specimen the reproducibility of the results on the dull nickel specimens was rather poor.

The fatigue limits for various types of nickel deposits, including commercial rolled nickel for comparison, are given in Table XV along with the tensile strength, elongation, Young's modulus, and the endurance ratio. Two different values of the fatigue limit were obtained for dull nickel deposits, depending on whether the smooth surface (originally adjacent to the stainless steel starting sheet) or the less smooth outer surface was stressed in tension. The latter arrangement gave the lower result. The table shows that the fatigue limit increases with the tensile strength of the deposit and therefore is much higher for the bright nickel deposits than for the Watts-type deposits. The average endurance ratio of the ten deposits in Table XV is close to 0.5, which is considerably higher than the endurance ratio of about 0.34 possessed by metallurgical nickel.

G. Yield Strength

The yield strength is probably of minor importance in determining the engineering applications of nickel deposits. Interest in this property arose in connection with the scattering of the results sometimes observed in the measurements of the fatigue limit of dull nickel deposits. This scattering was at first ascribed to the plastic deformation that took place in the early stages of the endurance test, and it was inferred that a low yield strength of electrolytic nickel might be responsible for the poor reproducibility. It was thought desirable, therefore, to have some data on the yield strength of nickel deposits, especially since no such data were available in the literature.

The yield strengths of eight representative specimens of nickel deposits were measured for an offset of 0.2 per cent. The stress-strain curves for three of the specimens were determined with the same equipment as that used for measuring Young's modulus of elasticity. Since the other five specimens were not thick enough to support the weight of an extensometer, the stress-strain curve was obtained in a somewhat less accurate manner from the automatically recorded motion of the head of the testing machine. The results of the two types of measurements were consistent. These measurements were made by M. L. Williams of this Bureau.

In Fig. 36 the yield strengths of the eight deposits are plotted against the tensile strengths, with representative data for metallurgical nickel for comparison. Unpublished data by C. E. Heussner[30], shown on the graph by crosses, agree well with ours. The yield strength of the electrodeposited nickel varies almost linearly with tensile strength, whereas the yield strength of the metallurgical nickel varies in a more complicated manner. On an average the yield strength of the electrodeposits is about two-thirds of the ultimate tensile strength. Since the endurance limit of electrodeposited nickel is only about half of the tensile strength, a low yield strength cannot be responsible for the scattering of the results observed in the endurance tests.

H. Internal Friction

Internal friction is measured by the capacity of a solid to damp out elastic vibrations[174]. For example, if two bars were struck by a hammer, the one with the lower internal friction would ring the longer. The magnitude of the internal friction is measured by the decrease in vibrational energy per cycle in the specimen when vibrating freely and in this discussion will be represented by the logarithmic decrement d, where $d = \ln \frac{A_1}{A_2}$, A_1 and A_2 being the amplitudes of two successive cycles. No simple relation appears to exist between the internal friction of a metal and its other mechanical properties, and two steels of similar strength and hardness[36] may differ considerably in internal friction. The internal friction seems to be influenced most by residual stresses, such as those resulting from cold work, and by cracks. Cold working increases, and annealing decreases, internal friction. The interpretation of measurements of the internal friction of magnetic materials such as nickel is more difficult than that for other metals, because some of the dissipation of vibrational energy in the metal may be caused by the magnetizing and demagnetizing of domains. The internal friction of many metals and alloys has been measured, but no measurements have been reported on electrolytic nickel.

The internal friction was measured by setting the specimen into forced longi-

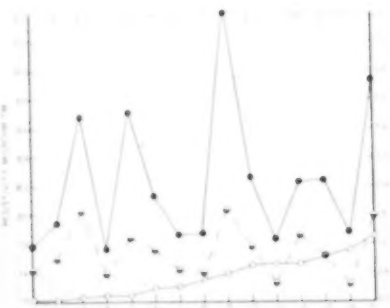


Fig. 38. Relation of resistivities of 15 nickel deposits from cobalt-containing baths ($NiSO_4$, C, and S) to cobalt content and to resistivities of corresponding cobalt-free deposits

tudinal vibration at its fundamental resonant frequency, removing the driving force, and then measuring the time of decay of the free vibrations between two known amplitudes. The resonant frequency is known from a calibration of the driving oscillator. In these experiments the velocity of sound was also measured and used to calculate Young's modulus. The velocity of sound was obtained by measuring the fundamental frequency of the specimen in longitudinal vibration. The specimen was supported at two points each of which was one-fourth of the length of the specimen from one of the ends, so that the length of the specimen was equal to the wavelength of the fundamental longitudinal vibration. The velocity of sound was calculated from the length of the specimen and its frequency of vibration. The measurements of internal friction and velocity of sound were made by H. L. Fusfeld of Frankford Arsenal.

Measurements were made on 13 different specimens of electrolytic nickel both as-deposited and after being annealed at 400° C. The data on the internal friction and velocity of sound are given in Table XVI along with the data for several other mechanical properties. The internal friction shows no consistent trend with the nature of the deposit. A bright nickel deposit is as likely to have a low internal friction as a dull Watts-type deposit. In general, annealing of the deposits resulted in a lowering of the internal friction and an increase in the velocity of sound in the deposit, thus indicating that stresses present in the as-deposited metal affect these properties.

The internal friction did not correlate well with other properties of the deposits. No relation was found to the stress during deposition or to the magnetic or electrical properties of the deposits. The relation between internal friction and hardness is shown in Fig. 37 for both as-deposited and annealed deposits and represents the best correlation found between internal friction and any other property. Even this correlation is open to some doubt, because four points (Table XVI, Nos. 5, 7, and 13 for as-deposited nickel and 6 for annealed nickel) are widely scattered. Three of these deposits had an unusually high internal friction and the remaining one, (f), was relatively hard. These points are not plotted in Fig. 37.

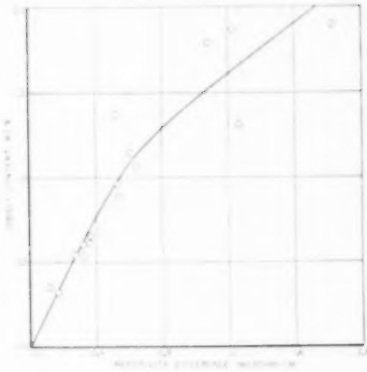


Fig. 39. Increase in resistivity of nickel deposits caused by the presence of cobalt. The increase in resistivity is determined by subtracting the resistivity of a cobalt-free deposit from that of a similar deposit obtained from the corresponding cobalt-containing bath

VIII. ELECTRICAL AND MAGNETIC PROPERTIES

A. Electrical Resistivity

The electrical resistivity is usually a good index of the purity of a metal because impurities always increase the resistivity. Less than one-hundredth of a per cent of a foreign element can often be detected by resistivity measurements[37]. The resistivity, therefore, has been used qualitatively to confirm the results of chemical analyses for small amounts of impurities when other disturbing factors were absent. Resistivity is also affected by the size and distribution of the impurities and by the soundness of the metal.

It was expected that the resistivity of nickel deposits would correlate well with the conditions of deposition, the content of impurities, and other physical and mechanical properties of the deposits, because in a similar study of chromium deposits[38] such a correlation was obtained. However, one difficulty arose that decreased the usefulness of the data on resistivity obtained in this study. The commercial nickel salts and anodes used in this country contain cobalt equivalent to several tenths of a per cent of the nickel content. Most of the deposits used in this investigation were obtained from baths made up with such materials. The variations in resistivity that resulted from the presence of cobalt in these deposits were sufficient to vitiate attempts to establish relations between resistivity and those plating variables which usually have only small effects on physical properties. However, correlations were readily obtained in instances in which the range of resistivity was greater than the fluc-

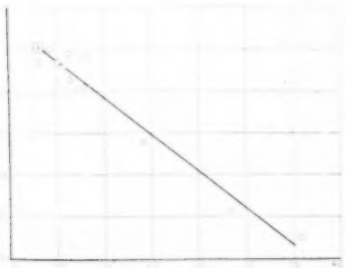


Fig. 40. General relation between resistivity and density of nickel tubes deposited from 13 different baths, including 6 bright nickel baths

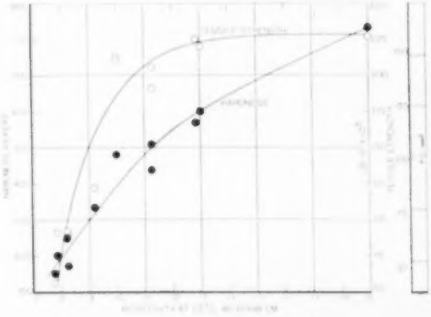


Fig. 41. General relation between resistivity and tensile strength, and resistivity and hardness, of nickel deposited from 17 baths, including 6 bright nickel baths

TABLE XVI. INTERNAL FRICTION, VELOCITY OF SOUND, STRESS, HARDNESS, AND TENSILE STRENGTH OF NICKEL DEPOSITS

Exp't No.	Bath	Temp. °C.	C.D. amp./dm.²	pH	Internal friction d (log. decr. $\times 10^{-4}$)		Velocity of sound				Stress		Hardness Vickers		Tensile strength			
							as-deposited		annealed 400° C.						as-deposited		annealed 400° C.	
					as-deposited	annealed 400° C.	ft./sec.	meter/sec.	ft./sec.	meter/sec.	lb./in.² ×10³	kg./mm.²	as-deposited	annealed 400° C.	lb./in.² ×10³	kg./mm.²	lb./in.² ×10³	kg./mm.²
1	S	55	5	3	23.5	24.7	15,051	4587	15,380	4686	17	12	202	...	66	46	..	
2	$S_{(1)}C_{(1)}$	10	2	3	29.4	14.2	14,691	4477	14,898	4539	41	29	251		...	..		
3		30	5	3	17.7	13.3	15,843	4829	16,099	4905	35	25	182	137	75	53	62	43
4		55	5	3	18.0	2.76–17.8*	16,077	4899	16,359	4985	17	12	150	147	56	39	53	37
5	$oS_{(1)}C_{(1)}$	55	5	3	106.3	26.7	15,300	4663	15,540	4735	15	11	142	...	60	42		
6	$S_{(1)}C_{(1)}$	55	5	3	18.5	110	14,677	4473	15,504	4724	31	22	212	138	74	52	64	45
7	$S_{(1)}C_{(10)}$	55	5	3	84.7	25.4	15,317	4668	15,688	4780	38	27	248	185	92	64	78	55
8	C	55	5	5	37.1	42.4	14,834	4521	14,951	4556	55	39	321	...	135	95		
9	oC	55	5	3	27.7	9.18	15,909	4849	16,086	4901	37	26	228		97	68		
10	Na	55	5	3	21.0	3.39	15,863	4835	16,193	4934	18	13	147	...	56	39	...	
11	NH_4	55	5	5.7	25.6	9.90	15,274	4655	15,430	4702	..	..	285	...	110	77		
12	Ac	50	5	4.5	35.7	16.5	15,902	4847	16,055	4892	25	18	335	142	147	103	68	48
13	f	65	5	3.7	20.5	25.3	15,867	4836	16,198	4936	15	11	509	202	206	144	83	58

*This specimen showed a marked amplitude effect after annealing. Variations in the final damping values are caused by varying the driving signal by a factor of two.

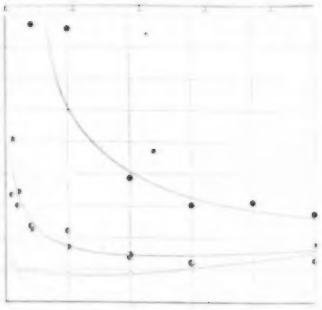


Fig. 42. Effect of current density on resistivity of nickel deposits

Curve 1 represents f bath at 65° C (149° F) at a pH of 3.7
Curve 2 represents $sS_{111}C_1$, sS_1C_1 baths at 55° C (131° F), at a pH of 3.0 and 5.0
Curve 3 represents $oS_{111}C_1$ bath at 55° C (131° F), at a pH of 3.0

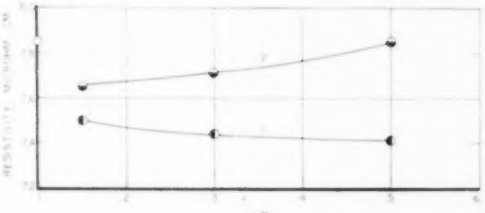


Fig. 43. Effect of pH of plating bath on resistivity of nickel deposited at 55° C (131° F) and 5 amp/dm² (46 amp/ft²)

Curve 1 equals $oS_{111}C_1$ bath
Curve 2 equals oC bath

tuations caused by the small cobalt content. Better correlations were obtained with cobalt-free deposits, although unfortunately the data from this source were not very numerous.

No systematic study of the relation between resistivity and the conditions of deposition of nickel deposits has been made previously, but some isolated measurements have been reported[3,40,130,138]. A value of 6.844 microhm-cm at 20° C has been reported for electrolytic nickel of 99.99 per cent purity[130], which corresponds to a value of 7.07 microhm-cm at 25° C (our standard temperature) using a temperature coefficient of 0.0064/° C. No further information concerning the specimen on which this value was obtained is available, especially as to whether the specimen was in the as-deposited state or whether it had been remelted and recast.

The resistivity values for cobalt-free deposits from the oS and $oS_{111}C_1$ solutions compare very favorably with those measured by Jordan and Swanger[40] on specimens of known composition and history. They obtained for annealed nickel wire a value of 7.24 microhm-cm at 20° C, corresponding to 7.48 microhm-cm at 25° C. The average of the resistivity values for the oS and $oS_{111}C_1$ deposits in the annealed condition is also 7.48 microhm-cm at 25° C. Likewise the value of Jordan and Swanger for cold drawn nickel wire is 7.53 microhm-cm at 25° C, compared with the average value of 7.52 microhm-cm at the same temperature for the oS and $oS_{111}C_1$ deposits in the as-deposited condition.

Only passing mention will be made of the ideas which have been put forth to explain the manner in which impurities affect the conductivity of metals. The impurities produce strains in the metal lattice which scatter the conducting electrons. The subject is further discussed from the point of view of quantum theory by Seitz[138] (p. 315). A somewhat different theory has been put forth by Raub[139], who worked with copper and silver deposited in the presence of organic addition agents. He ascribed the increase in resistivity to the insulation of the individual crystal grains by an envelope of nonconducting impurities. A similar idea was expressed by Merica and Waltenberg[28] in their study of the effect of sulfur in nickel.

Method of measurement. The resistivity of the nickel deposits was measured by comparing the potential drop across a nickel deposit of known dimensions (in the form of a tube or sheet) with that across a standard 0.001 ohm resistance in a series circuit. Separate contacts to the deposit were used for the current and the potentiometer leads. For the latter, knife edges 5 cm (2 inches) apart were used, and a potential balance was obtained with a sensitive potentiometer and galvanometer so that the effect of contact resistance was eliminated. The reproducibility of the measurements was within 1 per cent. The measurements were done at the prevailing room temperature, but all values given are calculated for a temperature of 25° C, using the temperature coefficient resistivity 0.0066/° C. To obviate variations due to thickness, all specimens were at least 0.13 mm (0.005 inch) thick.

1. *Effect of Cobalt Content*

A knowledge of the effect of cobalt content on the resistivity will be helpful in estimating the validity of the relationships based upon other factors. The data in Table III show that resistivity is the only property that is appreciably affected by the presence of small amounts of cobalt in the deposit. This subject has not been studied previously with respect to electrodeposits, although the effect of cobalt on the resistivity of nickel produced by metallurgical methods has been mentioned[17].

The effect of the cobalt content on the resistivity of nickel deposits is shown in Figs. 38 and 39. In Fig. 38 15 deposits from the cobalt-containing $S_{111}C_1$, C_1, and S solutions and 15 duplicate deposits from the corresponding cobalt-free solutions are shown. The deposits are arranged in increasing order of their cobalt content which is indicated by a black bar. The resistivity of the cobalt-containing deposit is shown by a cross hatched bar, and the resistivity of the corresponding cobalt-free deposit appears as a white bar

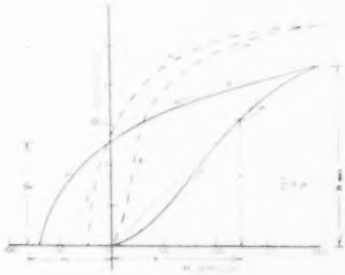


Fig. 44. Typical magnetization curves of nickel deposited at 5 amp/dm² (46 amp/ft²)
Curve A—$S_{111}C_1$ bath at 55° C (131° F) at a pH of 5.0
Curve B—f bath at 65° C (149° F) at a pH of 3.7

TABLE XVII. MAGNETIC PROPERTIES OF NICKEL ELECTRODEPOSITS

Hmax—Maximum Field Strength—200 Oersted

Dep. No.	Bath	Temp. °C.	C.D. amp./dm.²	pH	Bmax kilogauss	Br kilogauss	Hc oersted	μ max
1	$NiCl_2$	30	5	1.5	5.45	3.11	51.0	41
2		30	5	3	5.31	3.00	35.4	47
3		30	5	5	5.50	2.92	20.3	74
4		55	5	1	5.73	3.08	22.1	81
5		55	5	1.5	5.67	3.00	21.0	80
6		55	5	3	5.75	2.83	17.4	95
7		55	5	5	5.55	2.90	15.8	101
8		80	5	1.5	5.65	2.54	25.0	59
9	$nSn(C_6$	55	5	3	5.55	2.77	18.4	91
10		80	5	3	5.53	2.53	23.2	66
11	NH_4	55	5	3	5.52	2.70	16.7	69
12		55	5	5	5.52	2.15	24.0	56
13		55	5	5.5	5.28	2.19	29.1	47
14		80	5	3	5.43	2.32	26.7	54
15		80	5	5	5.40	2.17	29.2	46
16	Na	55	5	3	5.87	3.03	16.1	109
17	C	55	5	3	5.22	2.18	34.8	41
18		80	5	3	5.56	2.52	24.8	61
19	$S(C_6$	55	5	1.5	5.58	2.86	24.0	70
20		55	5	3	5.60	2.70	23.0	68
21	$S(C_{10}$	55	2	3	5.56	2.50	35.4	44
22		55	5	3	5.06	2.00	35.4	36.5
23	Ar	50	5	4.5	5.08	2.75	61.5	32.5
24	S	55	5	1.5	5.58	3.05	35.0	54
25	oS	55	5	1.5	5.41	3.10	35.7	56
26	F	55	5	4.5	5.53	3.08	23.0	74
27	$S_{10}C_6$-1N	55	5	5	5.73	2.87	20.1	88
28	f	65	5	2.3	5.29	2.27	38.4	35
29		65	5	3.7	4.61	2.45	71.5	25
30	OH	55	5	2.5	5.33	2.90	52.6	39
31	OH1	55	5	3.5	4.98	2.33	52.5	28.5
32	a		6		5.31	1.01	20.5	33
33			3		4.94	2.52	55	30
34	b		6		4.72	2.76	68	27.2
35			4		4.70	2.80	70.5	27
36	c		4		4.77	2.25	60.5	28
37	d		4		5.36	1.15	25.4	34.5
38	e		4		5.28	2.12	36.5	34

in the opposite direction. The dotted line represents the average resistivity of cobalt-free deposits. This bar-graph demonstrates that the resistivity of the cobalt-containing deposits increases with the cobalt content. The resistivity also seems to depend on the resistivity of the pure nickel deposit, as represented by the white bars. For example, the resistivities of cobalt-containing deposits 13 and 14 (cross hatched bars) seem out of order. This discrepancy can be explained by the higher resistivity of pure nickel deposit 13 as compared with 14. A similar situation exists with respect to specimens 1 and 3, and 8 and 9. The uncertainty of the cobalt estimations caused by the difficulties of estimating small amounts of cobalt in the presence of large amounts of nickel may be partly responsible for these deviations.

The relation between cobalt content and resistivity is still more clearly shown in Fig. 39, in which the difference in resistivity of deposits from the cobalt-free and the corresponding cobalt-containing solutions is plotted against the cobalt content of the latter deposits. This figure shows that the maximum increase in resistivity caused by the presence of cobalt in the deposits from the commercial plating solutions probably is of the order of 1 microhm-cm. Such cobalt-containing deposits will not be likely to have a higher resistivity than 8.5 microhm-cm. Therefore in order to derive relationships between the resistivity of cobalt-containing deposits and other physical properties or plating variables, it is necessary that the variations in resistivity be greater than 1 microhm-cm.

The data collected on the oxygen content of the cobalt-free deposits were not sufficient to permit a relationship to be established between the oxygen content of the deposits and the resistivity, as was done for the study on chromium deposits[52]. Most of the data on the oxygen content were obtained with the cobalt-containing deposits, and, since the effect of the oxygen on the resistivity was smaller than the effect of the cobalt, no relationship could be established. An attempt to correct the data for the increase in resistivity due to the cobalt was not successful.

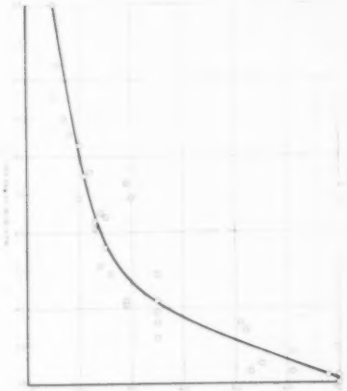


Fig. 45. General relation between coercive force and maximum permeability of nickel deposited from all types of baths under various conditions of deposition

μ max is the maximum permeability and is determined by drawing a line from the origin tangent to the magnetization curve. At the point of contact the magnetic permeability, $B/H = Y/X$, is at a maximum.

Br is the residual induction and is determined by the value of B when the applied magnetizing force is reduced to zero.

Hc, the coercive force, is determined by the strength of the reversed magnetizing force required to bring the magnetic induction of the specimen to zero. It is a measure of the ability of the specimen to resist demagnetization.

B max is the maximum magnetic induction produced in the specimen by a magnetizing force of 200 oersteds.

2. Relation Between Resistivity and Other Properties

A relation between resistivity and the other properties of the deposits is to be expected because the same basic factor—codeposited impurities—is presumably at the root of variations in all the properties. Unfortunately, most of the data on mechanical properties were for the cobalt-containing deposits, and correlations could not be established between the resistivity and other physical properties of the ordinary type of nickel deposits because the variations in the resistivity were rather small and probably were masked by the cobalt-contamination of the deposits. However, if all types of nickel deposits were considered, particularly those of bright nickel, the resistivities ranged considerably above the 8.5 microhm-cm limit which we had taken as the lowest value indicative of a significant trend. Fig. 40 shows an almost linear relation between resistivity and density of nickel tubes, and Fig. 41 shows a correlation between resistivity and tensile strength and hardness.

3. Effect of Conditions of Deposition and Bath Composition

The effect of the current density and temperature of deposition on the resistivity of nickel deposited from the cobalt-free Watts bath ($oS_{III}C_1$) was almost nil (Fig. 42, curve 3). The small variations noted at the extremes of current density may be within the experimental error. Deposits plated from the cobalt-containing baths, $S_{III}C_1$, S_1C_1, and f, at a low current density have a considerably higher resistivity than corresponding deposits from the cobalt-free bath. A comparison of curves 1 and 2 in Fig. 42 with the previously discussed Fig. 2 shows that the high resistivity is a result of the cobalt content of these deposits and not directly of the current density.

Variations in the *p*H of the plating solution have only a small effect on the resistivity of the deposits. This is illustrated in Fig. 43 for cobalt-free deposits from the Watts-type solution, $oS_{III}C_1$, and from the all-chloride solution, oC. The resistivity seems to be less sensitive than the mechanical properties as an index of the nature of the deposit, as the deposits plated from the all-chloride bath at a *p*H of 5 had higher values of mechanical properties but showed only a slight increase in resistivity.

The effect of chloride in the bath is to increase the resistivities of the deposits. This may be seen from Fig. 43 by comparing curve 1 for the Watts bath, $oS_{III}C_1$, with curve 2 for the all-chloride bath, oC. The average of the resistivities of 5 deposits from each bath indicated that the resistivities of the deposits from the chloride bath were about 0.25 microhm-cm higher. This trend of resistivity correlates with the greater hardness and tensile strength of the chloride deposits.

The influence of the nickel content of the plating solution on the resistivity of the deposit was not studied with the cobalt-free baths. Data were available only for the ordinary cobalt-containing solutions $S_{III}C_1$-1N, $S_{III}C_1$, and $S_{III}C_1$-4N. The average resistivity of 5 deposits (Table I, Nos. 20, 39, 41, 47, 56) from the 2N solution was 7.80 microhm-cm and the average of the corresponding deposits (Table I, Nos. 114, 117, 118, 119, 122) from the 4N solution was 8.76 microhm-cm. This difference of 1 microhm is significant, since the comparison was based upon deposits plated under the same conditions from solutions made up with the same salts. The difference is too large to be attributed to the fluctuations that result from variations in the cobalt content of the deposits. The higher resistivities of the deposits from the concentrated solution correlate with the higher values for their mechanical properties (See Fig. 28).

B. Magnetic Properties

The magnetic properties of a metal depend upon its physical state, and, in particular, upon factors such as crystal structure, internal stress, lattice distortion, and the presence and distribution of foreign substances. However, the relations between the magnetic properties and the physical state of a metal are not as simple or as apparent as those between mechanical properties and the physical state. As a corollary to this situation, the magnetic properties do not parallel closely the mechanical properties except in limited fields.

In general, lattice distortions cause a metal to have a relatively low magnetic permeability and a relatively high coercive force. The lattice distortions may result from internal stresses, such as those arising from cold work or from the presence of precipitated impurities highly dispersed. Since these same conditions also usually lead to hardening, a metal is sometimes referred to as being magnetically hard or, in the opposite situation, magnetically soft.

The literature contains numerous references to the magnetic properties of nickel prepared and treated by commercial metallurgical methods, but little information is available on the magnetic properties of electrodeposited nickel or on the correlation of magnetic properties with the conditions of deposition and with other physical properties[8, 9, 10, 11]. Some information is available on nickel films deposited by evaporation[6].

It has been shown that many of the variations in the properties of electrodeposited nickel may be attributed to the codeposition of impurities, with their attendant effects on crystal structure. Since magnetic properties of nickel deposits are affected by lattice strains that may be caused by the codeposition of impurities, it is to be expected that the magnetic properties also will vary with the conditions of deposition and that some correlation will exist between the magnetic and mechanical properties.

Method of measurement. The magnetic measurements made on the electrodeposits consisted of determining the magnetic induction of sheet specimens, 28 cm (11 inches) long and 3 cm (1.2 inches) wide, with a Fahy Simplex permeameter[28]. The

Fig. 46. Effect of chloride content of plating bath on magnetic properties of nickel deposits. Most of the points represent the average of two or more plating conditions

Fig. 47. Effect of temperature of plating bath on maximum permeability and coercive force of nickel deposited from $S_{III}C_{I}$, $aS_{III}C_{I}$, and NH_4 baths at 5 amp/dm² (46 amp/ft²), and a pH of 4.5, 3.0, and 5.0. Each point is the average of 3 to 6 deposits, each produced under different plating conditions

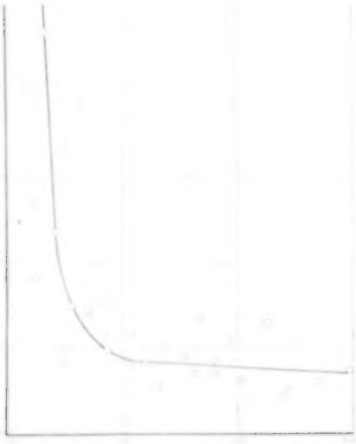


Fig. 48. General relation between maximum permeability and hardness of 37 nickel deposits produced from all baths under various conditions of deposition

magnetizing field was applied by means of a U-shaped electromagnet, across the poles of which the specimen was clamped. The actual observations consisted in noting the deflection of a ballistic galvanometer which was connected to test coils placed in the magnetic fields. The measurements were made by P. H. Winter of the Magnetic Section of this Bureau.

Measurements were made on 40 specimens in the as-deposited condition and on 5 annealed specimens. The data were plotted in the form of magnetization curves, in which the magnetic induction, B, of the specimen in kilogausses, was plotted against the magnetizing force, H, in oersteds, as shown in Fig. 44. The maximum magnetizing force applied was 200 oersteds. Fig. 44 also illustrates the important magnetic quantities obtained from the magnetization curves.

The reproducibility of the magnetic properties was not determined by running duplicate specimens. However, the overall reproducibility of the measurements and of the specimens may be inferred by comparing deposits which are known to be closely alike in physical properties, for example, the cobalt-containing and the cobalt-free deposits. From a comparison of Nos. 6, 9, and 16; Nos. 8, 10, 24, and 25 in Table XVII, we find that Bmax is reproducible to about 0.15 kilogauss, Br to about 0.1 kilogauss, Hc to about 1.2 oersted, and μmax to about 8.

Of these four magnetic properties, Hc and μmax showed the best correlation with conditions of plating and with other physical properties. The values of Bmax do not vary to a large extent because they all tend to approach the saturation value for nickel, which is about 6500 gausses[8]. At the maximum magnetizing force used in this investigation (200 oersteds) the saturation value for all specimens was not attained.

The data obtained are given in Table XVII. In Fig. 45 the inverse relation between the maximum permeability and the coercive force is shown. This general relation may be of use in decreasing the number of magnetic properties that need to be discussed in detail.

1. *Effect of Conditions of Deposition*

Of the variables involved in deposition, the factor having the most effect on the magnetic properties of the deposits was the type of plating solution. Table XVII shows that the coercive force of the bright nickel deposits (Nos. 28 to 38) is on the average about double, and the maximum permeability less than one-half, that of Watts nickel deposits, $S_{III}C_{I}$ (Nos. 1 to 10). The magnetic properties of deposits from other baths fall in between. The relatively lower magnetization of the bright nickel deposit is an indication of considerable internal stress or lattice distortion. These magnetic properties are consistent with the diffuse pattern of the deposits given by X-rays.

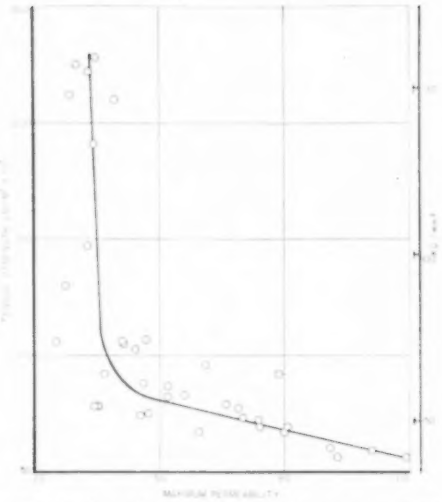


Fig. 49. General relation between maximum permeability and tensile strength of 36 nickel deposits produced from all baths under various conditions of deposition

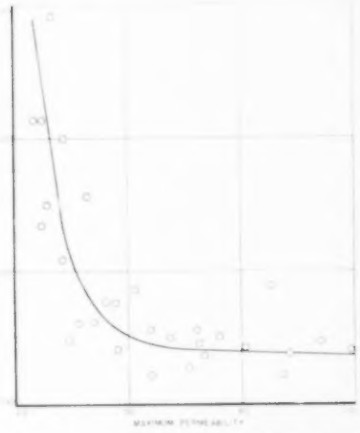


Fig. 50. General relation between maximum permeability and electrical resistivity of 29 nickel deposits produced from all baths under various conditions of deposition

The effect of chloride content of the bath on the magnetic properties of the deposits is shown in Fig. 46. The residual induction of the deposit decreases almost linearly as the chloride content of the plating solution increases. The coercive force and the maximum permeability exhibit, respectively, a minimum and a maximum for deposits from the solution containing 25 per cent of the nickel as chloride. These extremes in the curves are similar to those obtained when other physical properties are plotted against chloride content (see Figs. 26 and 27).

The variation in magnetic properties of deposits from the Watts-type solutions with the temperature of deposition is shown in Fig. 47. The coercive force is at a minimum and μ_{max} is at a maximum at an intermediate temperature of 55° C. A similar trend of stress, hardness and tensile strength with temperature of deposition has been noted previously.

Not enough data were available to determine whether the magnetic properties showed any trend with *p*H or current density. Also, no clear trend could be detected in a plot of maximum permeability or coercive force against the oxygen content of the deposits.

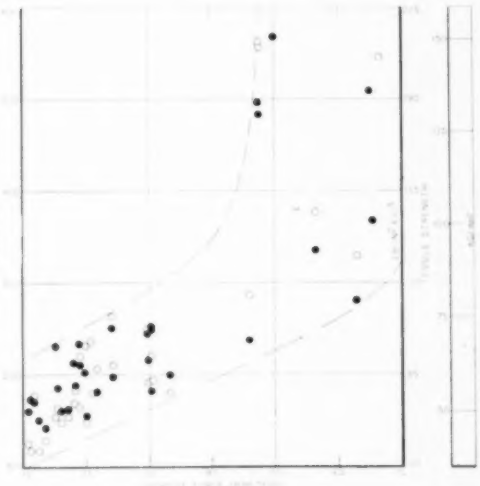


Fig. 51. General relation between coercive force and hardness and between coercive force and tensile strength of 32 nickel deposits produced from all baths under various conditions of deposition

Open circles represent tensile strength
Full circles represent hardness

2. *Correlation of Magnetic and Other Properties*

It was pointed out in the introduction to this chapter that some correlation between magnetic properties and other physical and mechanical properties is to be expected, since the variations in all the properties of the deposits are attributable to the same common factors. In con-

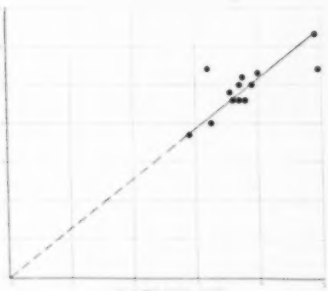


Fig. 52. Relation between magnetic induction of nickel deposits at a field strength of 150 Oersteds and the force required to detach a magnet (2 mm diam. x 50 mm) from the surface

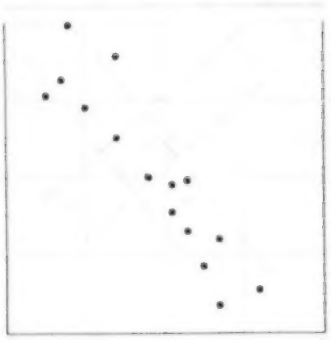


Fig. 53. General relation between stress and coercive force and between stress and maximum permeability of 15 nickel deposits produced from the $S_{III}C_3$, $oS_{III}C_3$, $S_{III}C_3$ (−1N), S_3C_3, S_3C_{III}, C, Na, and NH_4 baths under various conditions of deposition.

Open circles represent coercive force.

Full circles represent maximum permeability.

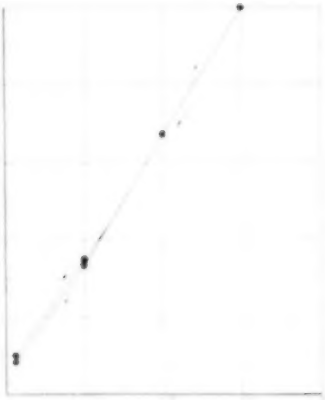


Fig. 54. Thermal expansion of nickel deposited from $oS_{III}C_3$ bath at 55° C (131° F), 5 amp dm² (46 amp ft²), and a pH of 3.0.

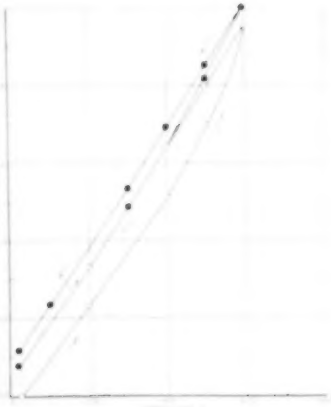


Fig. 55. Thermal expansion of nickel deposit, e (bright nickel), at 3 amp dm² (30 amp ft²).

Curve 1. first heating and cooling cycle.

Curve 2. second heating and cooling cycle.

Fig. 56. Thermal expansion of nickel deposited from Am bath at 55° C (131° F), 2 amp dm² (19 amp ft²), and a pH of 8.5.

firmation of this, the results of the preceding section show that variations in the conditions of depositions caused trends in the magnetic properties paralleling those of certain other physical and mechanical properties. In the following paragraphs the correlation between magnetic properties and a few properties will be examined more directly.

In Figs. 48, 49, and 50 the hardness, tensile strength, and resistivity are plotted against the maximum permeability. The points fall along the curves fairly well. High permeabilities appear to be related to low values of these three properties. The relation between the coercive force, hardness, and tensile strength (Fig. 51) is only fair, as the points show considerable scattering. In general, deposits with a coercive force below 50 oersteds have a hardness below 270 Vickers and a tensile strength below 75 kg mm² (107,000 lb in²).

The relation between hardness and magnetic properties has been investigated for other metals[57] but not for electrolytic nickel. Two different types of correlation may exist: (1) if the variation in properties is the result of lattice strains introduced either by cold work or by a finely dispersed material, the hardness of a metal may vary directly with the coercive force and inversely with the permeability; and (2) if the variation in properties of a metal is the result of a foreign material forming a solid solution, lattice strains are less likely to be produced and no general relation may exist between magnetic properties and mechanical properties. Since we have seen that the magnetic properties of nickel deposits do parallel some of the mechanical properties, we may consider this fact as evidence that one of the factors that determines the properties of electrodeposited nickel is the presence of internal strains resulting from the presence of dispersed impurities.

5. *Measurement of Thickness of Nickel by Magnetic Pull*

One method[23] of measuring the thick-

ness of nickel coatings on nonmagnetic basis metals consists in determining the force required to detach a small permanent magnet from the nickel coating. Since the magnetic properties of nickel coatings from different sources vary somewhat, the usual procedure involves annealing the nickel-coated non-ferrous specimen at 400° C for an hour to bring the magnetic properties of various nickel coatings to a more uniform condition. This annealing is not required for nickel coatings plated on steel. In this investigation it was of interest to determine: (1) which of the magnetic properties most closely paralleled the pull of the permanent magnet; and (2) the reason for the variations in magnetic properties of nickel coatings as deposited.

With a Magne-gage the pull of a small permanent magnet of 36 per cent cobalt-steel 2 mm in diameter, 50 mm long was measured on various specimens of nickel sheet about 0.25 mm (0.01 inch) thick. These specimens had been plated on and detached from a stainless steel starting sheet. Since the specimens were not all of exactly the same thickness, a correction was made to put the measured magnetic pulls on the basis of coatings 0.25 mm (0.01 inch) thick. When the data were plotted against the various magnetic properties of the nickel deposits, the best correlation was obtained with the magnetic induction, B, at a magnetizing force of 150 oersteds. The points including those for annealed nickel fell on a straight line which seems to pass through the origin, as shown in Fig. 52. Hence, the magnetic pull is directly proportional to the magnetic induction produced in the deposit at a magnetizing force of 150 oersteds. Magnets of different strength probably would correlate best at other magnetizing forces.

The variation in the magnetic pull obtained with the different types of nickel coatings represented in Fig. 52 was much less than had been expected on the basis of earlier work on the magnetic method of measuring the thickness of nickel coatings[2]. The average deviation from the mean in the present experiments was only about 7 per cent. This small variation was further confirmed by the uniformity of the values of B_{max} in Table XVII. The greater variations in the magnetic properties of nickel coatings in the earlier experiments may be caused by the stress in the nickel coating, for the following reason. The magnetic measurements reported in this investigation were made on nickel sheets which had been stripped from stainless steel starting sheets, whereas, in the earlier experiments on thickness measurements, the pull of the magnet was measured on coatings adherently plated on a basis metal. In the present experiments the stress produced in the nickel during deposition was at least partly relieved when the specimen was removed from the stainless steel, as then

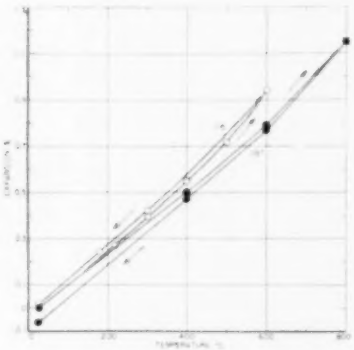
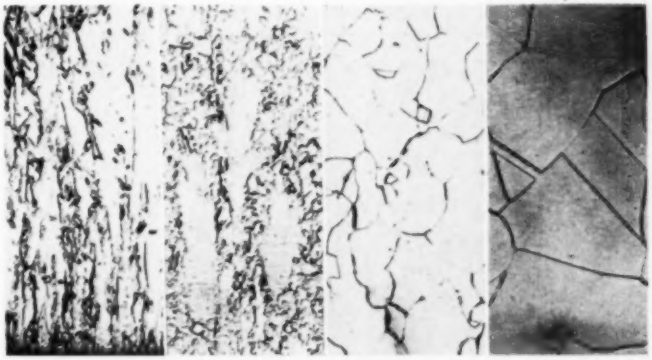
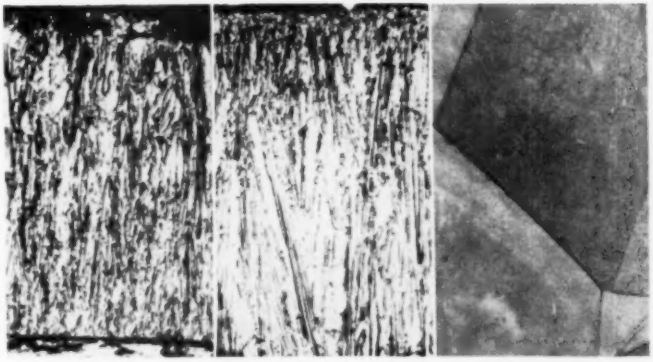


Fig. 57. Thermal expansion of bright nickel deposits produced at 55° C (131° F) and 5 amp dm² (46 amp ft²)

OB bath at pH of 2.5
OBT bath at pH of 3.5

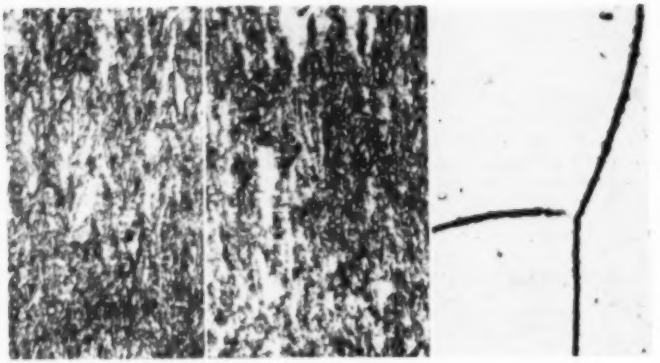


Deposits at 30° C (86° F) As-deposited (A) | *Heat-treated at 500° C (752° F) (B)* | *Heat-treated at 800° C (1472° F) (C)* | *Heat-treated at 1000° C (1832° F) (D)*

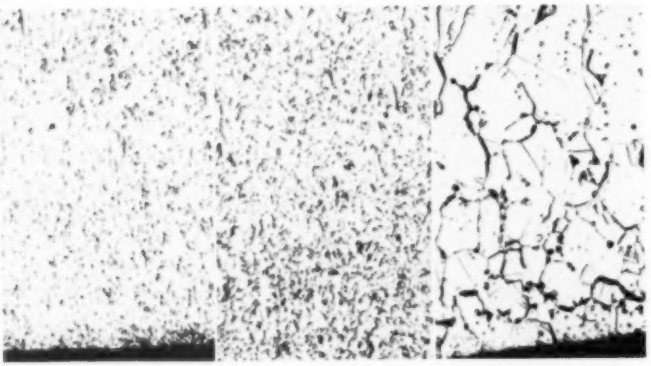


Deposits at 80° C (176° F) As-deposited (E) | *Heat-treated at 500° C (752° F) (F)* | *Heat-treated at 1000° C (1832° F) (G)*

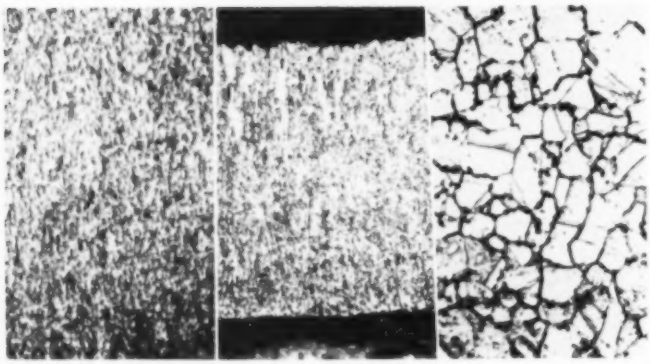
Fig. 58. Effect of heat-treatment on structure of nickel deposited from the $Ni(C_6H_5SO_3)_2$ bath at 5 amp dm² (46 amp ft²) and a pH of 3.0. Cross section x 250. Etchant: glacial acetic and nitric acid



(A) as-deposited (B) heat-treated at 400° C (752° F) (C) heat-treated at 1000° C (1832° F)



(D) as-deposited (E) heat-treated at 400° C (752° F) (F) heat-treated at 1000° C (1832° F)



(G) as-deposited (H) heat-treated at 400° C (752° F) (I) heat-treated at 1000° C (1832° F)

Fig. 59. Effect of heat-treatment on structure of nickel deposited at 55° C (131° F), 5 amp/dm² (56 amp/ft²), and a pH of 3.0. Cross section x 250. Etchant: glacial acetic and nitric acid

the nickel sheet simply contracted or expanded *en masse*. On the other hand, the nickel coatings which were tested while still in contact with the basis metal retained the plating stresses, which had a considerable effect on the magnetization of nickel.

The correctness of this explanation was demonstrated by the following experiment. Nickel coatings about 0.025 mm (0.001 inch) thick were deposited upon both sides of a copper sheet. The nickel coating on one side was then removed anodically so that its presence would not interfere with measurements made on the other coating. After the magnetic pull between a magnet and the coating was determined with a Magne-gage, the copper basis metal was dissolved in a mixture of chromic and sulfuric acids leaving the nickel sheet stress-free. The magnetic pull on this sheet was again measured. The data in Table XVIII, column 9, show that the relief of the stress in the deposit caused a considerable increase in the magnetic pull, amounting to over 60 per cent for two of the deposits (Nos. 2 and 3). Since the stresses in deposits 1 to 4 inclusive were tensile, which would reduce the magnetization of the nickel deposit, the magnetic pull was increased by relieving the stress. The stress in deposit 5 was compressive, so that on relieving the stress the magnetic pull should decrease, as was actually the case. The magnitude of the changes in the magnetic pull do not follow closely the magnitude of the stress in the deposit. However, it is possible that after more investigation the change in the magnetic pull of the coating may be used as a measure of the stress.

The last three columns in Table XVIII show that the magnetic properties of the coatings further improved after they had been annealed at 400° C. The percentage increases in pull were of the same order of magnitude for the first 4 specimens, but on the average were not as large as that obtained by dissolving the basis metal to relieve external stress. The annealing relieved the internal stress in the deposits. If the nickel coatings had been annealed while still on the basis metal, the same total change would have been obtained because all stress would be relieved.

Although the bulk or external stress in nickel deposits is relieved when the specimen is separated from the basis metal, Fig. 53 shows that there is a correlation between the stress present in deposits during deposition and the magnetic properties. Deposits from solutions containing organic compounds have been excluded in making this correlation. Since magnetic properties are sensitive to stress, this correlation may be taken as further evidence that along with the bulk or external stress in the deposits, which can be measured with a contractometer, there exists a certain degree of internal stress that can be relieved by annealing only.

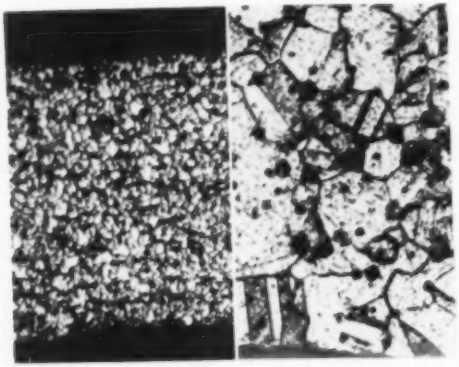
TABLE XVIII. EFFECT OF RELIEF OF STRESS ON MAGNETIC PROPERTIES OF NICKEL DEPOSITS AS DETERMINED BY THE PULL OF A MAGNET

Expt. No.	Bath	Temp. °C	C.D. amp/dm²	pH	Stress lb/in² × 10⁶	Stress kg/mm²	Pull in g (Magne-gage readings) as-deposited	stripped	diff.	% change	400° C annealed	diff.	% change
1	$S_{III}C_1$	55	5	5	25 (tensile)	18	1.62	1.85	0.23	14	2.00	0.15	8
2	C	25	5	2.5	42 (tensile)	29	1.02	1.75	0.73	72	1.99	0.24	14
3	Ac	25	5	4.5			0.96	1.54	0.58	60	1.74	0.20	13
4	Am	90	4	9.5	9 (tensile)	6	1.27	1.31	0.04	3	1.42	0.11	8
5	OB	55	5	3.2	—4 (compressive)	—3	0.58	0.55	—0.03	—5	0.73	0.18	32

TABLE XIX. COEFFICIENTS OF LINEAR THERMAL EXPANSION OF ELECTROLYTIC NICKEL

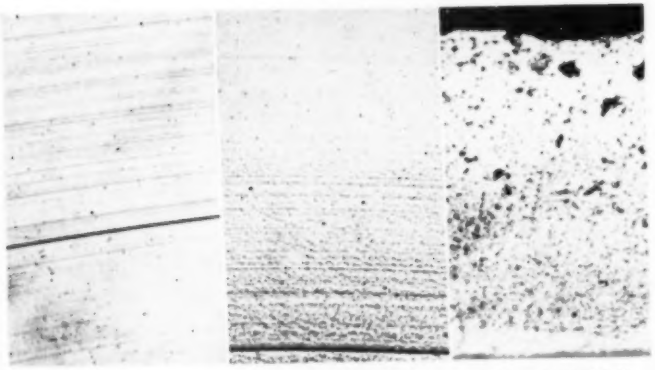
Expt. No.	Bath	Temp. °C	C.D. amp/dm²	pH	Test	Average Coefficients of Expansion per Degree C × 10⁶: 20° to 100° C	20° to 200° C	20° to 300° C	20° to 400° C	400° to 500° C	500° to 600° C	20° to 600° C
1	$S_{III}C_1$	55	5	3.0	1st heating	13.4	13.9					
					1st cooling	13.4	14.2					
					2nd heating		14.1	14.5	14.9[a]			
					2nd cooling	13.5	14.1		15.4			
2	C	55	5	5.0	1st heating	11.8	12.2	[b]				
					1st cooling	13.7	14.5					
					2nd heating		14.3	[c]				
					2nd cooling	13.3	14.0		15.4			
					3rd heating	13.3	14.0	14.7	15.2	10.6[d]	34.3[e]	
					3rd cooling		14.2	14.8				15.6
3	$oS_{III}C_1$	55	5	3.0	1st heating	13.5	14.0	14.6	15.2	16.4	16.2	15.5
					1st cooling		14.1	14.9				15.7
4	e		3	...	1st heating	13.3	13.3	13.3	13.6[f]	19.6	25.4	16.7
					1st cooling	13.3	13.7	14.4				15.1
					2nd heating			14.4			19.9	16.0
					2nd cooling				15.1	16.0	15.7	15.4
5	OB	55	5	2.5	1st heating	13.6	14.0	14.1	14.5	16.3	22.5	16.2
					1st cooling		14.1	14.1				15.9
6	f	65	5	3.6	1st heating	12.3	12.8	13.3	13.7[g]	16.7	16.7	14.8
					1st cooling		13.7	14.4			17.1	15.6
7	electrolytic nickel fused in vacuum, annealed, cold swaged, and annealed[i]					13.3	13.9	14.4	15.1[h]	15.9	16.9	15.5

[a] Irregularity in expansion between 300° and 400° C.
[b] Expansion irregularity between 210° and 231° C, probably due to evolution of hydrogen.
[c] Reduced rate of expansion between 200° and 400° C, probably due to evolution of hydrogen.
[d] Reduced rate of expansion between 400° and 500° C, probably due to evolution of hydrogen.
[e] Marked increase in rate of expansion between 500° and 600° C, probably due to evolution of gas (oxygen).
[f] Irregularity in expansion between 300° and 400° C (magnetic transformation).
[g] Irregularity in expansion between 300° and 400° C (magnetic transformation).
[h] Irregularity in expansion near 350° C (Curie point).
[i] Data from the literature (40).

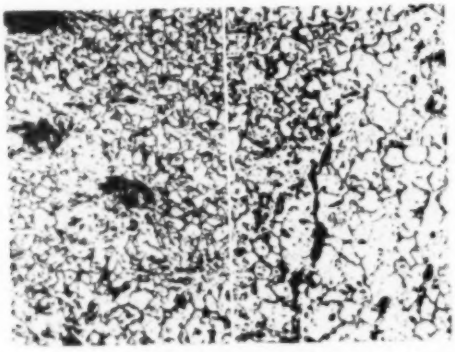


Heat-treated at 1000° C (1832° F) *Heat-treated at 1400° C (2552° F)*

Fig. 60. Effect of heat-treatment on structure of nickel deposited from the C bath at 55° C (131° F), 5 amp/dm² (46 amp/ft²), and a pH of 5.0. Cross sections x 200



As-deposited *Heat-treated at 600° C (1112° F)* *Heat-treated at 1000° C (1832° F)*



Heat-treated at 700° C (752° F) *Heat-treated at 800° C (1472° F)*

Fig. 61. Effect of heat-treatment on structure of bright nickel deposit, a, produced at 4.3 amp/dm² (40 amp/ft²). Cross sections x 250. Etchant: glacial acetic and nitric acid

IX. THERMAL PROPERTIES

A. Thermal Expansivity

The thermal expansivity of a metal is an important physical property which must be taken into consideration for engineering applications at elevated temperatures. Differential expansion between a coating and a basis metal may be important, since, if it is large, it may lead to cracking of the coating when heated. The cracking of chromium deposits when heated while still on the basis metal is a familiar example; however, chromium deposits that are separated from the basis metal may be heated without cracking. Although the literature on the thermal expansion of nickel and nickel alloys is voluminous, no data are available on electrodeposited nickel.

Method of measurement. Most of the measurements of the thermal expansion of the nickel deposits were done by the precision micrometric method, as described in detail by Hidnert and Souder[59]. The specimens were electroformed, thick-walled nickel tubes 25 cm (10 inches) long and 0.7 cm (0.27 inch) in diameter. The measurements consisted in determining the change in length of the tube (which was in a horizontal position) at each temperature with a traveling comparator on which two micrometer microscopes were mounted horizontally. These measurements were made by Peter Hidnert of the Optics and Metrology Division of this Bureau.

Some less accurate, but more rapid, measurements were made with an apparatus of fused silica described by Hidnert and Souder[59]. The specimens were nickel tubes about 7.5 cm (3 inches) long. The specimen was placed in a long fused-silica tube closed at the bottom. A fused-silica rod rested on top of the specimen and communicated the expansion of the specimen to a dial gage resting on the upper end of the silica rod. The tube that carried the specimen was placed in a horizontal electric muffle furnace, but was inclined upward at an angle sufficient to cause the silica rod to rest firmly against the top of the nickel specimen. The use of the muffle obviated the need of the specially constructed furnace described by Hidnert and Souder.

Measured expansivities. Six specimens of electrodeposited nicked were examined by the precision method and three specimens by the fused-silica dilatometer method. The data for the former six runs are given in Table XIX along with data from the literature[60] on a specimen (No. 7, Table XIX) of metallurgically treated nickel for comparison. The average coefficients of thermal expansion (Table XIX) in the lower temperature intervals did not differ significantly from that of specimen 7. The curve shown in Fig. 54 represents data for deposits from the $oSm_{III}C_1$ and is an example of normal behavior. The expansion curve is fairly

straight and the heating and cooling curve follow about the same path. On cooling to room temperature, the specimen returned nearly to its original length.

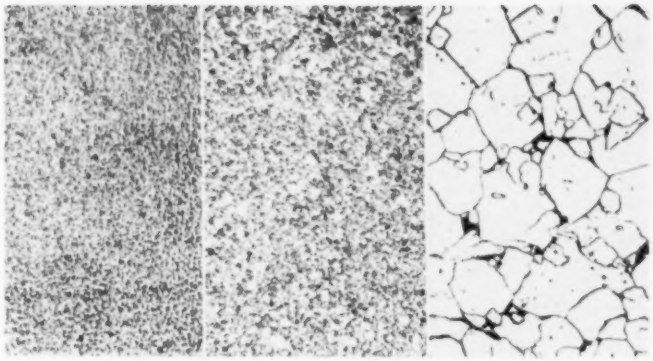
Several of the nickel deposits, e.g., e and Am (Figs. 55, 56), showed a marked increase in thermal expansion in the temperature range above 500° C. The cooling curve followed a different path from the heating curve and, on cooling the specimens to room temperature, they had changed their original length. An intermediate type of behavior, exhibited by the semi-bright and bright nickel deposits OB and OBT, is illustrated in Fig. 57. The curves show a departure from a straight line at the upper range of temperature, but the cooling curve retraces the heating curve and the specimen returns almost to its original length.

The probable cause of the irregularities in the thermal expansion curves is the presence in the deposit of impurities that decomposed into gaseous products leaving a porous structure. The extent of the deviation of the curves from a smooth curve is likely related to the content of impurities in the deposit. As an example, two deposits from the all-chloride bath, C, differed markedly in behavior. The deposit obtained at a *p*H of 3 expanded normally similarly to Fig. 54, but the deposit obtained at a *p*H of 5 expanded abnormally above 500° C, similarly to Fig. 55. This latter deposit contained much more included matter (see Table IV, Nos. 50 and 51) than the one plated at a *p*H of 3, and on cooling to room temperature its length had changed permanently. This indicates that the deposit changed in density also on being heat-treated. In general, a correlation exists between the irregular expansion of specimens and their change in density on heat-treatment. The subject will be discussed further in section X.

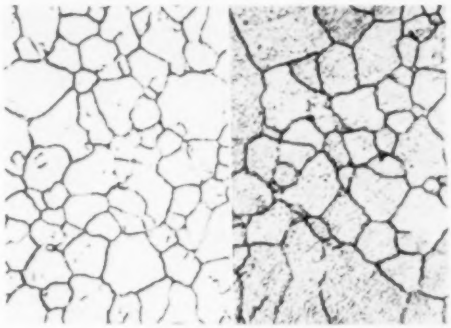
B. Specific Heat and Heat of Solution

The specific heat and the heat of solution of electrodeposited nickel is of no practical importance, but for possible correlation with other properties it was of interest to determine if bright nickel differed from dull nickel with respect to these properties. The specific heats were measured by Th. B. Douglas of the Heat and Power Division of this Bureau in the manner described in a recent publication of this Bureau[97]. The average values of the specific heat for the interval between 0 and 94° C was 0.1073 ±0.0002 cal/g/degree for the dull nickel deposit and 0.1083 ±0.0002 cal/g/degree for the bright nickel. The specific heat of bright nickel was about 1 per cent higher than that for dull nickel. Both values were within the range of values given in the literature[138] for various types of nickel.

The heat of solution was determined with sheet specimens less than 0.025 mm (0.001 inch) thick in order that they should dissolve readily. The solution used consisted of 250 g of chromic acid, CrO_3, and 100 ml of concentrated hydrochloric acid made up to one liter. This work was done by E. Newman of the Minerals Products Section of this Bureau. The heats of solution of bright nickel and dull nickel, each in the as-deposited and in the annealed state, four different specimens in all, amounted to 1.564 ± 1 cal/g and were the same within the experimental error.



As-deposited — *Heat-treated at 400° C (752° F)* — *Heat-treated at 600° C (1112° F)*



Heat-treated at 800° C (1472° F) — *Heat-treated at 1000° C (1832° F)*

Fig. 62. Effect of heat-treatment on structure of bright nickel deposited from the OBT bath at 55° C (131° F), 5 amp dm² (46 amp ft²), and a pH of 3.5. Cross sections x 250. Etchant: glacial acetic and nitric acid

X. HEAT-TREATMENT OF NICKEL DEPOSITS

A. Effect on Structure

All nickel deposits when heat-treated undergo a change of crystal structure, the extent of which depends upon the temperature. As seen under the microscope, the crystal growth of a cross section of a deposit shows several characteristic stages as the temperature of heat-treatment is increased. A number of investigators[6,37,77,108,116,127,134] have studied the structural changes in nickel deposits after heat-treatment and the accompanying changes in physical properties, but they do not agree on the temperature at which recrystallization starts. Probably this depends on the nature of the deposit and the conditions of heating.

In this study deposits were heat-treated in vacuo to prevent oxidation of the nickel. The period of heat-treatment was 1 hour at the specified temperature. Usually only minor changes in crystal structure occurred when deposits were annealed at 400° C (752° F), as can be seen by comparing the appropriate photomicrographs in Fig. 58. At more elevated temperatures, such as 600° C (1112° F) to 1000° C (1832° F) a radical change took place, and nearly all deposits acquired a similar structure of equiaxial grains regardless of the conditions of deposition. The main

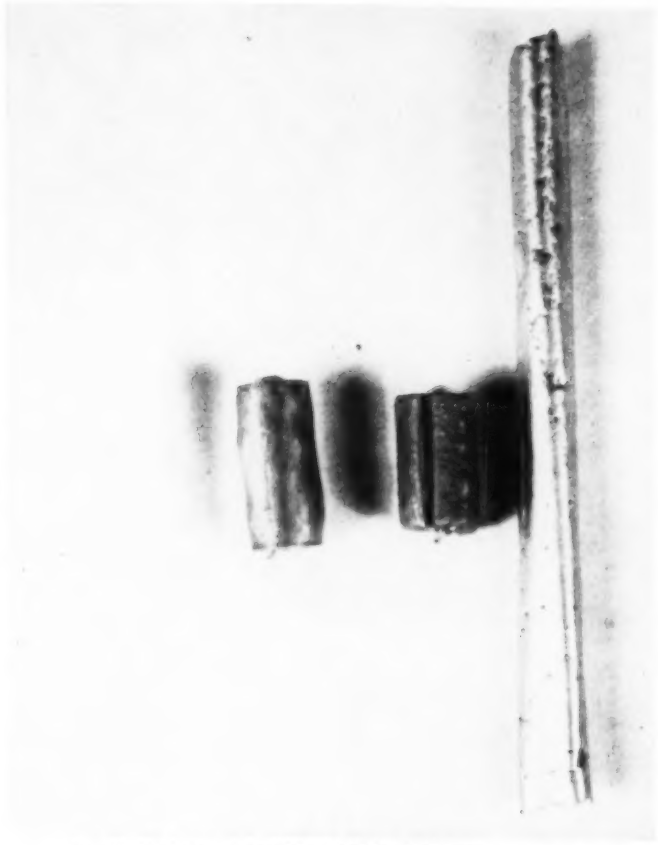


Fig. 63. Distortion and cracking of bright nickel deposit, a, resulting from heat-treatment. Temperature of heat-treatment from left to right: 600° C (1112° F), 800° C (1472° F), and 1000° C (1832° F)

difference in the resulting structures was in the grain size. The grain boundaries usually became well defined, and it is probably here that most of the nonmetallic impurities were segregated. The structural changes were accompanied by corresponding changes in physical properties, which will be reported in following sections.

The appearance of the cross-section of a deposit which has been heat-treated at 1000° C (1832° F) yields a rough indication of the purity of the deposit. This procedure was used by Gardam and Macnaughtan[47] in studying the relation between oxide content and the hardness of electrodeposited nickel. In Fig. 58 the photomicrographs of the $S_{III}C_I$ deposits that had been heated to 1000° C (1832° F) show that the grains and the grain boundaries were relatively clean. By way of contrast, the photomicrographs of the S_IC_{III} and C deposits (Fig. 59, F and I) show the presence of either inclusions or voids, both within the grains and at the grain boundaries. The heat-treated bright nickel deposits (Figs. 61 to 62) usually show the presence of more inclusions and porosity than do the deposits from entirely inorganic plating solutions, although exceptions occurred. The correlation between the appearance of the heat-treated deposits and the content of impurities in the deposits was only *fair*. The cleanest deposits were the $S_{III}C_I$ (Fig. 58, D and G) which contained about 0.01 per cent of oxygen, while the S_IC_{III} deposits (Fig. 59, F), which contained about 0.03 per cent of oxygen, showed considerable black material in the photomicrograph. On the other hand, the photomicrographs of the deposits from the C and the Ac bath (Fig. 59) seem to show the presence of a considerable amount of extraneous matter, although the oxygen content of the deposits was relatively low (slightly over 0.01 per cent). The presence of just over 0.01 per cent of chloride in the C deposit may have contributed to the inclusions revealed by the photomicrograph.

The evidence for believing that some of the dark areas shown in the photomicrographs of the heat-treated deposits are voids, which have become filled during polishing of the specimen, is that the density of some of the specimens decreased as a result of the heat-treatment. The changes of density will be considered in more detail later, but it may be of interest to examine at this point the porous structure of one deposit from the C bath which decreased 10 per cent in density after being heat-treated (Fig. 60).

The effect of heat-treatment on the structure of the bright nickel deposits is of particular interest because these deposits all have a larger total content of impurities, and, on being heat-treated, undergo more striking changes in structure and in physical properties than deposits obtained from inorganic plating solutions. In Fig. 63 are shown photographs of tubes of a certain bright nickel after heat-treatment. The heat-treated tubes warped and blistered badly and became visibly porous after annealing at 1000° C (1832° F). The structures of several heat-treated bright nickel deposits are shown in Figs. 61 and 62. In Fig. 61, the deposit showed initially the characteristic fine-grained, laminated structure. This structure could be seen even after a heat-treatment at 400° C (752° F), but a slight tendency for grain growth was also observable. At 600° C (1112° F) part of the fine structure still persisted, but the tendency for recrystallization into larger grains was evident, as were also the initial stages of porosity. At 800° C (1472° F) and 1000° C (1832° F) the deposit had recrystallized fully into larger grains and many pores or inclusions were clearly visible. The other bright deposits went through a similar series of changes.

B. Effect on Physical and Mechanical Properties

The mechanical properties, and to a lesser extent the physical properties of metals may vary with the heat-treatment. Electrodeposited metals may be affected to a greater extent than metallurgically prepared metals, because in the as-deposited condition they may have greater internal stress, smaller grain size, and foreign material in a finer state of dispersion. A simple heat-treatment, which involves only heating to a given temperature followed by slow cooling, relieves stresses within the metal and causes grain growth as well as agglomeration or redistribution of foreign material. These changes in the nature of the deposit result in considerable changes in those mechanical properties that are dependent upon or related to the crystal structure of the deposit, but they do not appreciably affect other properties, such as density and resistivity unless the deposit has a relatively high content of impurities.

Method of heat-treatment. The specimens

were heat-treated for 1 hour in an evacuated, stainless steel tube placed in an electric muffle. Most of the heat-treating was done at 400° C (752° F) or 1000° C (1832° F). Considerable difficulty was encountered in the heat-treatment of certain of the bright nickel specimens because they became very weak and brittle after annealing and were likely to fracture at the slightest impact. It was necessary to insert these specimens in a special fixture to keep them from warping or breaking. Because of the difficulty in handling these specimens, the values of tensile strength and elongation measured on them are not very accurate.

Effect of density and resistivity. The effect of heat-treatment on the density and resistivity of metallurgically prepared metals is usually rather small. Thus, the decrease in the electrical resistivity of a drawn nickel wire on annealing at 1000° C is of the order of a few per cent[40,104]. The behavior of nickel electrodeposits on annealing is quite variable, ranging from small changes in density and resistivity, comparable to those with metallurgical nickel, to changes of 10 per cent or more. The magnitude of the changes in density seems to be related to the content of impurities in the deposit (Fig. 64).

The effect of heat-treatment on the density and resistivity of nickel deposits is shown in Figs. 65, 66, and 67. The main points of interest are as follows: the density and resistivity of some specimens of nickel (curves 1, 6, 4, 9 in Fig. 65) changed very little on heat-treating, and their behavior, therefore, was similar to that of a fairly pure metallurgical nickel; other specimens of nickel deposits, from both the inorganic baths and the bright baths, changed considerably in density and resistivity. The changes in density and resistivity of these latter deposits were relatively small after a heat-treatment at 400° C; the large changes developed only after a heat-treatment above 500° or 600°

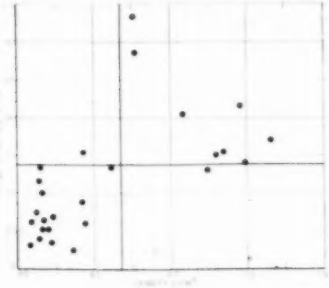


Fig. 64. Effect of content of impurities on density of nickel deposits annealed at 1000° C (1832° F). Deposits from most baths, including bright nickel.

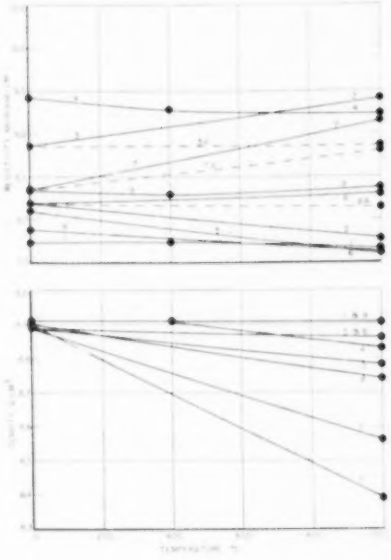


Fig. 65. Effect of heat-treatment on density and resistivity of nickel deposits from Watts-type solutions.

No. of curve	baths	Temperature C	Temperature F	Current density amp/dm²	Current density amp/ft²	pH
1	S $S_{III}C_l$ $\alpha S_{III}C_l$ Na	55	131	5	46	3.0
2	$S_{III}C_l$	10	50	2	19	3.0
3	$S_{III}C_l$	55	131	0.25	2	3.0
3A	*resistivity values of deposit in curve 3 corrected for volume change after heat-treatment.*					
4	$S_{III}C_l$	55	131	0.5	5	3.0
5	$S_{III}C_l$	55	131	5	46	5.6
6	$S_{III}C_l$	55	131	25	230	3.0
7	NH_4	55	131	5	46	5.5
7A	*resistivity values of deposit in curve 7 corrected for volume change after heat-treatment*					
8	NH_4	55	131	5	46	5.5
8A	*resistivity values of deposit in curve 8 corrected for volume change after heat-treatment*					
9	F	55	131	5	46	3.0

TABLE XX. RESISTIVITY AFTER HEAT-TREATMENT AT 1000° C (1832° F) CORRECTED FOR VOLUME CHANGE

Bath	Temp. °C	C.D. amp/dm²	pH	Density (g/cm³) as-deposited D_1	Density (g/cm³) Heat-tr. D_2	Resistivity (microhm-cm) as-deposited R_1	Resistivity (microhm-cm) Heat-tr. R_2	Resistivity corrected $\frac{D_2}{D_1} \times R_2$
$SnCl_2$	55	0.25	3	8.90	8.39	8.36	9.41	8.87
	55	5	5.5	8.90	8.84	8.14	8.36	8.30
C	55	5	3	8.90	8.64	8.24	8.64	8.38
	55	5	5	8.84	8.23	8.93	9.47	8.82
Cx	55	5		8.90	8.58	9.20	9.56	9.21
C (−N)	55	5	3	8.86	7.51	10.73	3.12	11.12
	55	5	5	8.85	7.92	9.62	10.33	9.24
	55	10	3	8.85	7.65	10.93	12.21	10.55
	55	10	5	8.82	7.54	9.54	10.50	8.97
NH_4	55	5	5.5	8.90	8.56	8.32	19.15	8.30
	55	5	5.7	8.90	8.74	8.19	8.29	8.14
Au	50	2	4.5	8.90	8.55	9.17	9.34	8.97

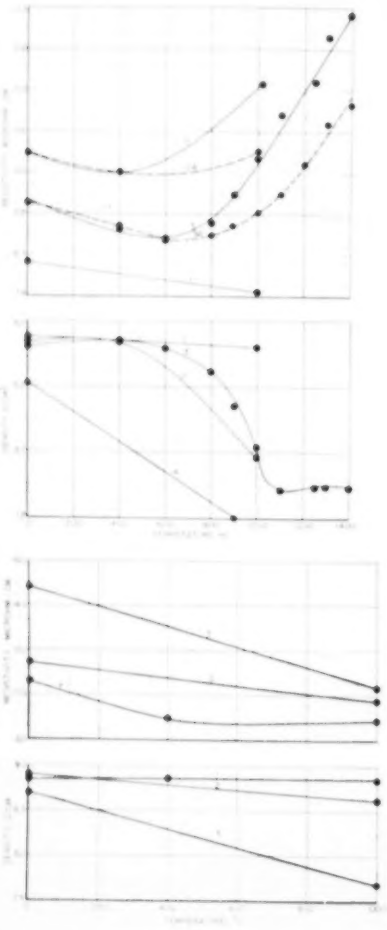


Fig. 66. Effect of heat-treatment on density and resistivity of nickel deposited at 55° C (131° F).

Curve 1 equals $SnCl_2$ bath at 5 amp/dm² (46 amp/ft²), and a pH of 3.0.

Curve 2 equals C, Cx, and C (−N) baths at 2 amp/dm² (19 amp/ft²) to 10 amp/dm² (93 amp/ft²), and a pH of 3.0 to 5.0.

Curve 2A equals resistivity values of deposits in curve 2 corrected for volume change after heat-treatment.

Curve 3 equals C bath at 5 amp/dm² (46 amp/ft²), and a pH of 5.0.

Curve 3A equals resistivity values of deposit in curve 3 corrected for volume change after heat-treatment.

Curve 4 equals Au bath at 2 amp/dm² (19 amp/ft²), and a pH of 8.5.

Fig. 67. Effect of heat-treatment on density and resistivity of deposits from bright nickel baths.

Curve 1 equals OBT and e baths.

Curve 2 equals f bath.

Curve 3 equals a, e, d baths.

C. Since most of the hydrogen was removed from nickel deposits by heat-treatment at 400° C to 500° C, the changes in density and resistivity cannot be attributed to the escape of hydrogen.

Two different types of behavior were shown by specimens that developed large changes in density and resistivity after heat-treatment at 1000° C: (1) the decrease in the density of deposits from the inorganic baths (Fig. 65, curves 3, 7, and 8; Fig. 66, curves 2 and 3) was paralleled by an increase in resistivity; and (2) the decrease in density of the bright nickel deposits (Fig. 67) was accompanied by a decrease in resistivity. The decrease in density of the deposits in both cases is probably caused by the formation of voids in the deposit as a result of the escape of gases, which are formed from the decomposition of inclusions. This explanation was first offered by Koster[117], who also pointed out that the parallel increase of resistivity, exemplified by case 1, was a result of the porous nature of the annealed metal. The measurement of resistivity is based on the apparent cross section and measured length of a specimen. If it is porous, the true cross section is smaller than the apparent cross section. If the resistivities measured in this study are corrected for the effect of the porosity of the metal by multiplying the apparent resistivity by the ratio:

$$\frac{\text{Density of heat-treated deposit}}{\text{Initial density of deposit}}$$

the corrected resistivities will be found to have actually changed very little as a result of the heat-treatment up to 1000° C. This is shown in Table XX and by the dotted curves in Figs. 65 and 66.

Unlike the deposits from the inorganic baths, the resistivities of the bright nickel deposits decreased considerably on heat-treatment, opposing the effect of the

porosity of the deposits. The initial resistivities of the bright nickel deposits were higher than those from the deposits from the inorganic baths, but on heat-treatment tended to approach those of the latter deposits. This result may be interpreted on the basis that the initial high resistivity was caused by the presence of inclusions of sulfur and carbon compounds which partially insulated the grain boundaries and produced high internal stresses in the deposits. On heat-treatment these impurities decomposed or agglomerated.

Effect on hardness, tensile strength, and elongation. The mechanical properties of electrodeposited nickel were more affected by heat-treatment than were the density and resistivity, probably because the mechanical properties are more sensitive to changes in crystal structure. The change in mechanical properties brought about by heat-treatment has been studied by a number of investigators[29,30,57,96,77,105,112,117,122,127,167] who were in general agreement that these changes are related to the changes in crystal structure. In particular, Roehl[30] has made a detailed study of the effect of annealing temperature on the hardness, tensile strength, and elongation of deposits from a Watts-type and a chloride bath. In general, his results agree with those obtained in this study.

For convenience in discussing the effect of heat-treatment on the mechanical properties of the electrodeposits, the latter are divided into 4 groups according to the magnitude of their mechanical properties in the as-deposited condition. The curves of hardness, tensile strength, and elongation shown in Fig. 68 are averages for the groups. Curve 1 represents the behavior of the Watts-type deposits; curve 2, the chloride type deposits; curve 3, the bright cobalt-nickel deposits, f; and curve 4, the bright nickel deposits. The first 3 groups of deposits differ considerably in their initial hardness, tensile strength, and elongation, but they all behave similarly on heat-treatment. The hardness of the three groups decreased to a common value of about 100 Vickers number and the tensile strength decreased to a common value of about 28 kg/mm² (40,000 lb/in²) after heat-treatment at 1000° C (1832° F). The hardness and tensile strength decreased in about the same proportion—approximately 45 per cent for curve 1 and 65 per cent for curve 2. The elongations of the 3 groups behaved similarly. The elongations reached a maximum value after a heat-treatment of 400° C (752° F).

It has been pointed out in the previous discussion that the elongation usually varied inversely with the tensile strength and hardness of the deposits. This relation was followed by the deposits heat-treated at 400° C (752° F), i.e., as compared with the initial deposits, the elongation increased and the hardness and tensile strength decreased. However the deposits heat-treated at 1000° C (1832° F) did not follow this relation, inasmuch as all three of the mechanical properties decreased.

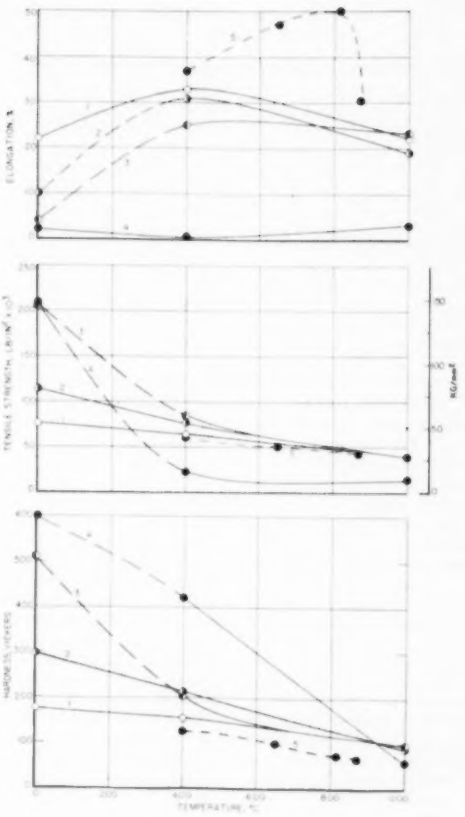


Fig. 68. Effect of heat-treatment on hardness, tensile strength and elongation of nickel deposited under various conditions of temperature, current density, and pH

Curve 1 equals S, oS, $S_{III}C_{I}$ and NH_4 baths
Curve 2 equals $S_{I}C_{III}$, C, C (−N), and Ac baths
Curve 3 equals f bath
Curve 4 equals OBT, a, c, d, e, baths
Curve 5 equals data from Roehl[30,139]
The dotted part of curves 2, 3, and 4 indicates that the shape of the curve is uncertain in this region.

The data of Roehl for deposits from a Watts-type solution are shown in Fig. 68 by dotted curves. The agreement with our data is fairly satisfactory. His data on elongation indicated that the temperature of heat-treatment for obtaining the maximum elongation of deposits was about 800° C (1472° F), whereas we found that the maximum elongation occurred in deposits heat-treated at about 400° C (752° F).

The bright nickel deposits, represented by curve 4 in Fig. 68, behaved in a considerably different manner from the other three groups. On heat-treatment the hardness and tensile strength decreased to lower values than for the other deposits, although initially these deposits had the highest hardness and tensile strength. The tensile strength fell off rapidly with heat-treatment. After a heat-treatment at 400° C (752° F) the tensile strength was only about 14 kg/mm² (20,000 lb/in²), whereas the other deposits still had retained a large proportion of their initial tensile strength. These bright deposits are somewhat brittle

TABLE XXI. EFFECT OF HEAT-TREATMENT AT 400° C (752° F) ON MAGNETIC PROPERTIES OF NICKEL DEPOSITS

Bath	Temp. °C	C.D. amp./dm²	pH	Bmax As-deposited	Bmax Heat-tr.	Br As-deposited	Br Heat-tr.	Hc As-deposited	Hc Heat-tr.	μmax As-deposited	μmax Heat-tr.
$S_{III}C_1$	55	5	3	5.75	5.96	2.83	3.11	17.4	15.3	95	127
C	55	5	3	5.22	5.83	2.18	3.16	34.8	26.6	41	80
S	55	5	1.5	5.58	5.86	3.05	3.30	35.0	29.3	54	78
Average change as result of heat-treatment				+7%		+21%		−18%		+57%	
a		3		4.99	6.50	2.52	4.65	55.0	12.8	30	260
OBT	55	5	3.5	4.98	6.30	2.33	4.92	52.5	8.1	28.5	350
Average change as result of heat-treatment				+28%		+97%		−80%		+935%	

Bmax = Maximum induction (at 200 oersteds).
Br = Residual magnetism.
Hc = Coercive force.
μmax = Maximum permeability.

initially, having an elongation of only a few per cent; but, unlike the other groups of deposits, heat-treatment does not improve their ductility. Thus, in general, the mechanical properties of the bright nickel deposits, with the exception of type f, are adversely affected by heat-treatment.

Effect on magnetic properties. The effect of heat-treatment on magnetic properties of the deposits was determined only at 400° C (752° F). The data for 5 different deposits are shown in Table XXI. The annealing caused B max, μmax, and Br to increase and Hc to decrease. These changes were not very large for the three deposits from the inorganic baths, but were considerable for the two bright nickel deposits, a and OBT. (See Table II.) In particular, after the heat-treatment, the bright nickel deposits, having the highest maximum permeability and the lowest coercive force, became more magnetic than the others.

XI. SUMMARY

A. Discussion of Data

The details concerning the magnitude and range of physical and mechanical properties of nickel electrodeposits which are contained in the preceding sections may be summarized as follows: The most important factor that determines the properties of the deposits is the type of solution. Variations in the operating conditions have relatively small effects, provided the conditions are within the satisfactory operating range for the solution used. The effects of bath composition and operating variables upon properties, as observed in this study, are in essential agreement with data in the literature. Minor disagreements, like the effect of potassium ions on hardness or the hardness of deposits from the all-sulfate solutions have been noted in the preceding sections.

The large effect of bath composition on the properties of electrodeposited nickel is illustrated in Fig. 69 which shows the considerable changes in properties of a deposit from a Watts bath when two organic addition agents are added successively, thus converting the Watts bath into a bright nickel solution. In this figure, O on the abscissa represents a Watts bath, $S_{III}C_1$, without addition agents; OT represents the same bath after the addition of Triaminotolyl-diphenyl-methane-chloride (reduced fuchsin) in concentrations of 5 to 10 mg/l; OB represents the Watts bath after the addition of nickelbenzenedisulfonate, 7.5 g/l; and OBT represents the bath with both addition agents to produce the fully bright deposit. A considerable increase in hardness and resistivity resulted after the addition of reduced fuchsin, thus showing that minute concentrations of organic impurities can change radically the properties of the deposit. It may be noted in Table I that the properties of the OBT deposits (Nos. 233 to 236) are similar to those of the proprietary bright nickel deposits (Nos. 208 to 230). Therefore the choice of a particular type of bright nickel depends less on the physical properties, since all the bright nickels are much alike in this respect, than on the ease of operation and control in the plant.

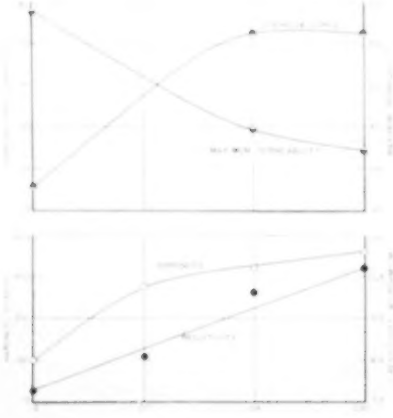


Fig. 69. Change in physical properties (hardness, resistivity, coercive force, and maximum permeability) of nickel deposits as organic brighteners are added stepwise to a Watts nickel bath.

O, $S_{III}C_1$ bath no additions
OT, $S_{III}C_1$ bath plus 5 mg/l reduced fuchsin
OB, $S_{III}C_1$ bath plus 7.5 g/l nickel benzenedisulfonate
OBT, $S_{III}C_1$ bath plus both addition agents (bright nickel bath)

For the purpose of classification the nickel baths may be divided into three main groups according to the magnitude of the physical and mechanical properties of the deposits:

(1) the Watts type solutions, including $S_{III}C_1$, o$S_{III}C_1$, $S_{III}C_1$–1N, $S_{III}C_1$–4N, Na, K and NH_4 baths; (2) the chloride type baths, including S_1C_{III}, C, C–4N, oC and Ac; (3) the bright nickel baths, a, b, c, d, e, f, OB, OT and OBT. This classification is for the purpose of convenience and as an aid to the memory since no sharp line of demarcation actually exists between the properties of deposits from

these groups. Some of the properties of a given deposit may fall in one group and some in another. Thus the deposits from the all-sulfate solutions, S and oS, do not fall clearly into any one group although they resemble most the deposits from the Watts bath.

The range of properties of the three main groups of nickel deposits is shown by blocks 1, 2, and 5 in Fig. 70. In addition, two intermediate types of nickel deposits, S and S_1C_1, are shown by 3 and 4 respectively. Seven important properties are shown: Stress, hardness, tensile strength, elongation, resistivity, coercive force and maximum permeability. The scales have been so chosen that the range of each property occupies about the same length of ordinate. For comparison, the properties of the $S_{III}C_I$ deposits have been chosen as the basis of reference, and the numbering of the scales have been arranged to make the properties of the $S_{III}C_I$ deposits fall almost on a horizontal line determined by the tops of the blocks. The values used for each block represent the average of a number of plating conditions, as indicated in the legend of Fig. 70. This figure shows that the deposits from the three groups vary considerably in properties. The fact that the heights of the blocks for 1, 2 and 5 are in the same order for all properties demonstrates the parallel trend of the physical and mechanical properties of the deposits of a given type. The Watts-type deposits (block 5) have the lowest stress, hardness, tensile strength, resistivity, and coercive force and the highest elongation and magnetic permeability. The bright nickel deposits (block 1) are the opposite, having the highest hardness, tensile strength, resistivity and coercive force and the smallest elongation and magnetic permeability. Most other nickel deposits can be assigned to one of these main groups. Thus, the deposits from the fluoborate bath, F, belong to the Watts-type group, whereas the deposits from the ammoniacal bath Am approach the bright nickel deposits in properties, especially with regard to hardness, tensile strength and resistivity.

B. Theoretical Discussion

The explanation which has been offered in this study for the magnitude and the large range of values of the physical and mechanical properties of electrodeposited nickel is contained in the following postulate: The properties of an electrodeposit are determined primarily by the chemical and physical nature of codeposited impurities. The codeposited material may directly influence the properties of the deposit or it may have important effects on the structure[20], producing a fine-grained structure perhaps with lattice distortion and internal stresses. These latter factors also influence the physical and mechanical properties of the deposits. In this manner the codeposition of foreign material affects, directly and indirectly, the physical and mechanical properties of deposits. A corollary to this is: substances present in the plating solution affect the properties of the electrodeposit only to the extent that they influence the codeposition of foreign material.

This hypothesis is based on the numerous correlations that have been discussed. First, the parallel trend of many of the properties shows that a common cause underlies their variations so that a single explanation should suffice for most of the observed details; next, correlations have been shown to exist between the properties and the microstructure and X-ray structure of the deposits; and finally, since the largest changes in structure and in properties result from variations in the nature of the plating solution, particularly in the presence of certain types of ions or minute amounts of special additions, it is reasonable to assume that the special character of the deposits is caused by the codeposition of various kinds of foreign matter which may vary in quantity as well as in effectiveness.

However the most convincing evidence for the role of the codeposited material is that in some instances direct correlations exist between the variations in properties and the content of foreign material. The correlations are not always consistent, probably for two reasons: (1) the degree of dispersion of the foreign material may be of importance, just as it is in the precipitation hardening of metals (a factor which cannot be evaluated readily because inclusions that are visible under the microscope are probably too coarse to have a large effect); and (2) equal contents of impurities may not produce equivalent effects, for example, the foreign material codeposited from a chloride solution may be more effective than that from a sulfate solution. Furthermore, the concentration of some of the codeposited materials may not be capable at present of analytical determination, for instance small quantities of chlorides.

The general tenor of this discussion is that those electrodeposited coatings that are of value in industry are not pure metals, but owe their valuable properties to the presence of small amounts of impurities. The smooth, thick electrodeposits with which the plating industry deals are actually exceptional because metals, if pure, would be expected to form, whether from melts or from plating solutions, as a mass of large crystals and not as a coherent deposit. Many electrodeposits can be obtained as coarse crystals from certain types of aqueous solutions, for instance silver and lead from nitrate solutions. Such deposits are very likely much purer than the coherent type of deposit. Electrodeposits obtained from fused melts also consist usually of a loose aggregation of crystals, probably because the inhibiting effects of adsorption on crystal growth do not operate so well at elevated temperatures.

The mechanism by which foreign material is codeposited is a matter of speculation, but very likely it is an adsorption phenomenon rather than an electrochemical one, as has sometimes been postulated. The adsorption mechanism is sufficiently broad and versatile to explain the very specific effects of certain additives to the plating solution and the influence of the anion of a plating solution on the nature of the deposit. This mechanism is probably capable of being tested by a study of the adsorption of substances on freshly electrodeposited metal surfaces with the aid of radioactive tracers. Future research should be directed towards the study of these adsorption phenomena and the processes taking place in the cathode film during electrolysis. More delicate methods of analysis for the small amount of impurities usually present are needed in order to correlate the content of foreign material with lattice distortion and crystal structure which is believed to be the basis for the observed large differences in physical and mechanical properties of nickel electrodeposits.

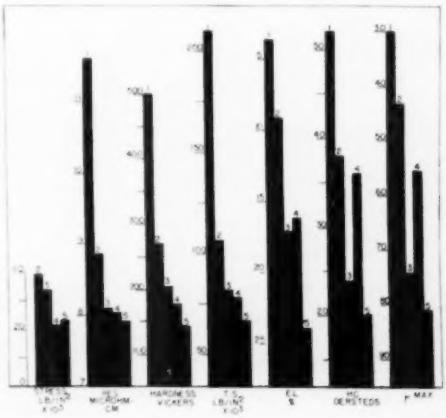


Fig. 70. Range and trend of physical properties of nickel deposited from 5 different types of baths, each point is the average of the properties of 5 or more deposits obtained under various conditions of plating

1 equals a, b, c, d, e, f, OB, and OBT baths
2 equals S_1C_{III}, C, Ac, C (−4N) baths
3 equals S_1C_1 bath
4 equals S and oS baths
5 equals $S_{III}C_I$, $oS_{III}C_I$, $S_{III}C_I$ (−1N), NH_4, Na, and F baths

XII. ACKNOWLEDGMENTS

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The Seymour Manufacturing Company, Seymour, Conn.
The Udylite Corp., Detroit, Mich.
W. Canning and Company, Ltd., Birmingham, England

XIII. APPENDIX

(a) Analytical reagent nickel sulfate, manufactured by Mallinckrodt, was used with the following maximum limits of impurities:

	per cent
Alkali salts	0.10
Chloride (Cl)	0.000
Cobalt (Co)	0.002
Iron (Fe)	0.000

(b) The cobalt-free Mond nickel shot was analyzed spectrochemically before use. No cobalt was detected. The metal contained only traces (less than 0.01 per cent) of silver, aluminum, calcium, copper, iron, magnesium, silicon and tin. The hydrochloric acid used was Baker & Adamson, C.P. reagent.

(c) The hydrogen peroxide used was Albone, manufactured by Du Pont, containing about 30 per cent by weight.

(d) Nickel hydroxide was prepared by adding C. P. Baker's analyzed sodium hydroxide, dissolved in distilled water to a nickel sulfate solution, prepared from Mallinckrodt analytical reagent nickel sulfate. The precipitated nickel hydroxide was washed thoroughly, made into a slurry with distilled water and kept in a stoppered bottle.

(e) Analytical reagent nickel carbonate, manufactured by Merck & Company, was used.

(f) C. P. Baker's analyzed barium hydroxide was used.

(g) The activated carbon was Darco Grade S-51, manufactured by Darco Corporation, New York.

(h) To test the effectiveness of the described purification method, three nickel deposits from the $S_{III}C_I$ (Watts), the C (all chloride) and the S (all sulfate) solutions, prepared at a temperature of 55° C, a current density of 5 amp/dm² and a *p*H of 3.0 were analyzed spectrochemically before the actual plating of the specimens started. The results of the analysis are as follows in the table below.

(i) Spectrochemical analysis of the electrolytic nickel anodes disclosed only traces (less than 0.01 per cent) of silver, aluminum, calcium, copper, iron, magnesium, lead, silicon and tin.

(j) The cobalt-free nickel anodes used in the cobalt-free solutions were also analyzed spectrochemically. Cobalt was detected only as a trace constituent and estimated to be approx. 0.001 per cent. Otherwise these anodes contained the same metals in trace amounts as the ordinary nickel anodes with the exception of silver and tin, which were not detected by spectrochemical analysis.

Solutions	$S_{III}C_I$	C	S
aluminum, %	<0.001 FT	<0.001 FT	<0.001 FT
calcium, %	<0.001 FT	<0.001 FT	<0.001 FT
copper, %	0.001 T	<0.001 FT	<0.001 FT
iron, %	<0.001 FT	<0.001 FT	<0.001 FT
magnesium, %	0.001 T	0.001 T	0.001 T
manganese, %		<0.001 FT	
lead, %	0.01 VW	0.001 T	0.001 T
silicon, %	0.001 T	<0.001 FT	<0.001 FT
tin, %	<0.001 FT	.....	<0.001 FT
zinc, %	.....	.....	.....

Designation: VW—very weak, estimated less than 0.01%
T —trace, estimated about 0.001%
FT—faint trace, estimated less than 0.001%

These three deposits were also analyzed for cobalt by a spectrophotometric method and contained:

Solution	$S_{III}C_I$	C	S
cobalt, %	0.54	0.96	0.46

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Abstracts of Convention Papers

Use of Ion Exchange Resins in Purification of Chromic Acid Solutions, by Lloyd Gilbert, Rock Island Arsenal, W. S. Morrison and F. H. Kahler, Illinois Water Treatment Company, Rockford, Ill.

The accumulation of metallic cation impurities in chromic-acid plating or anodizing solutions leads eventually to the necessity for discarding all or a portion of the solution, thereby giving rise to waste disposal problems as well as a loss of valuable chemicals. The development of styrene ion-exchange resins which will withstand chemical attack by chromic acid permits the use of ion-exchange techniques for the removal of the harmful contaminants.

In a practical working installation at Rock Island Arsenal both plating and anodizing solutions are treated batchwise in a single unit, although it is necessary to dilute the plating solutions to 100 g/l before they can be treated. After its passage through the ion exchange unit, an anodizing solution is ready for reuse, but a diluted plating solution is concentrated in a glass-lined vacuum evaporator. The distilled water obtained from the concentrating operation is used to replace evaporation losses in process tanks.

In a typical treatment of a 5000-gal batch of spent anodizing solution the removal of aluminum, iron and trivalent chromium was, respectively, 99.8, 99.5 and 94.8 per cent complete. The purity of the solutions after ion exchange is extremely high, and the decationized chromic acid is extremely corrosive. Some materials of construction which would normally be resistant to attack fail quickly and must be replaced by materials which have been tested in decationized chromic acid. A resistance reduction of as much as 65 per cent may result from the ion exchange treatment, thereby leading to significant reductions in power costs.

In the case of plating baths, where the sulfate content is important, the use of sulfuric acid to regenerate the cation exchange resin is completely practical, and the sulfate content is but little affected.

Cost data indicate a very favorable economic situation. The equipment will pay for itself in a short time on the basis of chromic acid savings, but to this must be added the benefits of reduced power costs, conservation of chemicals and reduction of waste disposal problems.

Filtration—Theoretical and Practical, by Harold W. Faint, Industrial Filter and Pump Manufacturing Company, R. Scott Modjeska, Scientific Control Laboratories, Chicago, Ill.

Developments in filtration over many years have led in the plating industry to the almost universal use of enclosed pressure filters comprising a drum or tank containing a filtering stack fed from a pump and discharging through a non-restrictive outlet. Clogging of dense diaphragm materials in the filter stack is avoided by the use of filter aids, often based on diatomaceous earth. The flow of liquid through the filter aid obeys Poiseuille's equation for smooth flow through capillary tubes; hence, the radius of the capillary canals through the filter aid has a tremendous effect on the pressure drop across the filter and the flow velocity through it.

The variables which govern filtration operations are filter area, filter pressure, nature of solids, ratio of liquids to solids, density of the liquid, extraction rate, temperature and resistance of cake and cloth. The shape of the particles of solids is important in the selection of the type of filter cake as well as the pressure to be used. The actual extraction of the solids from the liquid may take place by several mechanisms, namely, direct contact or interception, ion attraction, diffusion, inertial effects or agglomeration. Filtration efficiency may be easily judged by observation of the Tyndal cone effect.

Practical installations require careful planning of suction lines, pumps, precoat slurry tank, the filter itself and the effluent lines. In addition to discussions of the details of each of these items, systematic checklists are given to assist not only in the planning of an installation but also in the locating and correcting of troubles, should they arise. The entire filtration system should be under complete control by adequate valve installations. If the valve system becomes complex, operators should be thoroughly trained in its operation while the unit is filled with water. Proper training in other operations, such as precoating, will also pay large dividends in filtering efficiency.

Plastics as Plating Room Engineering Materials, by D. Gardner Foulke, American Electroplaters' Society, Newark, N. J.

Both thermosetting and thermoplastic materials have found practical uses in the plating room, but owing to their superior chemical resistance, the thermoplastic resins enjoy a wider usage.

The selection of tanks and tank linings has been complicated by the increasing use of high-speed baths, bright plating solutions, high temperatures and unusually corrosive solutions. Tanks made of fiber glass impregnated with polyester resins serve well for pickle baths as well as for plating solutions for hard chromium, nickel, cadmium, etc. Unplasticized polyvinyl chloride resins show promise, but difficulties in the manufacture of either solid or lined equipment limit their use at present. The highly chemical resistant polyethylene and similar resins are difficult to use

because of lack of adhesion to steel or other metals, although recent developments may change this situation. High-temperature Lucite has expanded the usefulness of the polymethylmethacrylate resins. The selection of any tank lining should involve rigorous tests for compatibility with the exact solution being used, particularly in bright plating processes.

Although ceramic materials are widely recommended for construction of ventilating systems, plastics are attractive for this application because of their light weight and excellent chemical resistance. Duct work of unplasticized polyvinyl chloride resin may be expensive to install, but it will be economical in the end. Ducts made of asbestos with a silicate binder lack chemical resistance, but impregnation with a synthetic resin produces a promising material. The polyester-fiber glass combination offers great promise inasmuch as it is easily handled and fabricated and ingredients are readily available.

Phenol-formaldehyde and polymethylmethacrylate resins are widely used for barrel plating equipment. Anode bags and diaphragms made of cotton are improved by impregnation with plastics, and Nylon fabrics also find use here. Many miscellaneous uses of plastics in the plating room are discussed, e. g., silicones in high temperature paints, plastic masks, plastisols for rack coatings, and organically modified bentonites which are useful in thickening plastisols for use as trowelled tank linings.

Materials of Construction for Plating Rooms, by R. E. Harr, Western Electric Company.

Materials of construction for floors, drains, piping, exhaust systems and tanks are discussed for a plating shop where zinc, nickel, copper-nickel, copper-tin, silver, chromium and gold are electrodeposited and where a number of other finishing processes such as anodizing and chromate treatments are in use.

The well-drained floors are constructed on a concrete base made with lightweight aggregate which is covered with four layers of asphalt-impregnated asbestos felt laid in hot asphalt and separated from a fifth layer by a slip joint of two layers of oiled kraft paper. The floor is finished with two layers of asphalt-silica mastic. Tanks as well as expanded metal gratings for walking areas are mounted on asphalt-coated concrete footings.

Drains are constructed of a chromium-nickel-copper-molybdenum-silicon alloy which is machinable and has adequate corrosion resistance.

Hydrochloric acid is stored in rubber-lined tanks and conducted to working tanks in rubber hose and pipe made of a copolymer of vinyl-vinylidene chloride. Nitric acid is handled in 18–8 stainless steel, and black iron serves for 20 per cent liquid caustic. Aluminum or plastic pipes are used for deionized water.

Exhaust systems are constructed of steel lined with three sprayed coatings of Gilsonite asphalt resin which are applied to carefully prepared surfaces and finished with two sealer coats of a modified phenolic base resin applied by brush or spray.

Unlined steel tanks are used for alkaline and cyanide solutions, whereas stainless steel, polyvinyl-chloride-lined or rubber-lined tanks are employed for most acid solutions. Rinse tanks should be constructed of stainless steel or monel metal, or lined with polyester resin reinforced with fiber glass for long life and freedom from contamination. Outside surfaces of tanks are protected with vinyl-base coatings.

Vacuum Metallizing Today, by J. Gordon Seiter, Manager, Vacuum Metallizing Department, F. J. Stokes Machine Company, Philadelphia, Pa.

Vacuum metallizing is a coating process wherein the work to be treated is placed in a high vacuum along with a piece of the metal which is to be deposited. This piece of metal is heated electrically to a temperature sufficient to vaporize it, and the vapors, which move away from the source along straight lines, condense on the cold work pieces to provide a bright continuous coating. Some metallic salts may be vaporized and condensed in the same way for special purposes, such as the application of non-reflective films to optical glass parts.

Inasmuch as the basis materials on which the films are deposited need not be electrically conducting, heat resistant or solvent resistant, almost anything may be coated by the process, the only limitation being that the work must not continuously evolve gas when placed in a high vacuum. Although a great many metals can be used to provide the coating material, aluminum is commonly employed because it is easily vaporized and gives a coating which looks like polished platinum. The aluminum can be lacquered for abrasion protection and for color.

The coatings obtained by vacuum metallizing are thin but extremely uniform and continuous. The process is inexpensive compared to electroplating or the deposition of metals by chemical reduction; hence, it can be used to advantage in many applications where thin decorative or reflective films are required.

Lacquering is an important phase of the metallizing process. It may be used as an undercoater to make the surface of the workpiece smooth or to seal pores and prevent gas evolution which would impede or prevent metallization. Lacquers may be applied to the metallized work for abrasion protection and to provide any desired color. The lacquers must be carefully selected in order to be compatible with the requirements of the process.

Current Distribution in Mechanical Plating. A Statistical Study, by William C. Geissman and Robert A. Carlson, National Lock Company, Rockford, Ill.

Contrary to usual opinion, barrel plating in a cyanide-zinc bath did not produce work which was uniformly plated with respect to thickness, as revealed by a statistical study of extensive, well-controlled data on coating thicknesses of production parts.

The investigation was based on thickness measurements made by the drop-test technique on pieces

plated in a 15-barrel unit. Complete plating details are given. Five groups of samples of 5 or 12 units each were taken from specified locations in each barrel, and identical areas were used for measurements on each piece.

Results were plotted as three standard deviations versus several variables. It is evident that the total variation in thickness for a given barrel load increases as the deposit thickness increases. There is no correlation between standard deviations and surface area of the load or the plating time. A line of best fit was calculated for three standard deviations versus average plate thickness, and lines parallel to this three standard deviations higher or lower encompassed all of the experimental points. Similar results were obtained with data from 30 barrel loads of carefully controlled work area. It was thus proven conclusively that control lines had been established for the barrel plating process under study.

For use in shop guidance, the data were used to construct curves of minimum plate thickness versus average plate thickness, i. e., the lines on the graph show, to various specified degrees of certainty, the average thickness that must be maintained by the plater in order to meet a specification for minimum thickness. It is shown that for a specified minimum of 0.2 mil the average thickness for 99.9 per cent certainty is 0.37 mil whereas for 50 per cent it is 0.31 mil; thus, a small change in average thickness represents a large change in the certainty of meeting the specification.

Bright White-Brass Plating, by R. B. Saltonstall, The Udylite Corporation, Detroit, Mich.

Although white-brass is not a coating which is a satisfactory alternate for nickel in applications involving severe exposure, it has many uses as an undercoat for chromium on parts intended for mild exposures. The alloy which is deposited may contain from 10 to 25 per cent of copper, and is easily obtained from a high-caustic cyanide bath. It has been found that the concentration of the constituents is not so important as the ratios of Zn:Cu, NaCN:Cu and NaOH:Cu, which should be, respectively, 2.7, 6.9 and 5.0.

When bright white-brass deposits are compared with those of bright nickel, it appears that of eight requisites which any substitute for bright nickel should possess, bright white-brass coatings are reasonably satisfactory on six counts. All of these relate to the application of the deposits. It is only in the properties of the deposits that serious limitations are encountered.

So far as the application of the alloy is concerned, readily available materials can be used in conventional equipment with cleaning, plating and control practices which involve nothing difficult or unusual. The bright deposits adhere well to properly prepared steel and brass parts as well as zinc-base die-castings, with or without preliminary deposits of copper or zinc, and they can be easily plated with bright chromium.

Bright white-brass deposits are definitely inferior to nickel with respect to ductility and corrosion resistance. The lack of ductility of the white-brass in conjunction with the internal stress of the chromium limits practical thicknesses of the alloy to a maximum of 0.2 mils, otherwise cracking occurs. Heat treatment only aggravates the cracking tendency. Bright white-brass forms bulky, unsightly corrosion products under severe exposure conditions, and chromium plating does not prevent this behavior. A copper undercoat is not effective in enhancing the corrosion resistance. White-brass is anodic to steel and protects it sacrificially. In the salt-spray test, white corrosion products appear in 6–8 hr. for the best deposits.

A Critical Review of Substitute Finishes, by Myron Ceresa, Westinghouse Electric Corporation, East Pittsburgh, Pa.

The factors aside from availability which must be considered in choosing a substitute metallic finish are appearance, corrosion resistance and cost of the deposit as well as the equipment and trained personnel which are available. The absence of a firm, long-range governmental policy on restrictions and allocations further complicates the picture. The scarcity of nickel is at present the most pressing problem.

Many possible or suggested substitute coatings for nickel are discussed in detail. Some involve reduced thicknesses of nickel augmented by other coatings, and others provide complete substitution. Copper-chromium finishes have been widely accepted for indoor use and when protected by clear baked enamel will serve for outdoor exposure on non-functional indoor applications. Nickel should be reserved for use on functional parts, particularly those which will receive outdoor exposure. It is emphasized that the method of plating copper which is used to replace all or part of the nickel is a factor in the performance of the coating.

Another approach to the problem of conserving nickel involves the use of plating practices which will give the least spread between maximum and minimum thickness, thereby making the best use of the available nickel. Although changes in design of the work to eliminate deep recesses is one approach, the plater can help by careful racking and the use of auxiliary anodes. Smoother basis metals and the use of bright-nickel solutions to avoid metal loss by buffing will improve the corrosion resistance of nickel-chromium finishes of given thickness. Where copper-chromium is used, the throwing power of chromium may be improved by better racking, intermediate anodes or by use of PR with the Wes-X cyanide solution which yields copper that is more easily covered by chromium than acid-copper deposits.

Extensive tables summarize uses, specifications, basis metal treatments, performance, etc., for a variety of substitute finishes.

Special Plating Plant Instrumentation and Apparatus, by Frank K. Savage, Savage-Rowe Plating Company, Kalamazoo, Mich.

Although ammeters, voltmeters and thermometers may be considered to be the basic instruments used in the plating room, there are other specialized instruments which may be employed to increase quality of plating as well as to reduce costs. Some special adoptions of instruments are presented, usually in connection with a specific problem.

Automatic *p*H control by means of glass electrodes which actuate feeding pumps through suitable indicating and recording equipment contributes dramatically to the smooth operation of baths which are sensitive to this variable.

The reuse in boilers of process-steam condensate from the plating room is safe only if the condensate is uncontaminated by solution which might enter through leaks in coils or heat exchangers. A conductivity cell in the common return line may be used to detect contamination, sound a warning signal and actuate a valve which diverts the condensate from the boiler.

Control of solution level in hot tanks is troublesome and erratic unless an automatic control is used. Float-actuated controllers are inferior to a device which employs probes which open and close electrical circuits that control suitable feed pumps. In the event of electrical failure, the system stops functioning, and no overflows have ever been experienced. This is in contrast to float-controlled valves which sometimes stick in the open position.

In the plating of complicated work, the plater may make use of bipolar electrode systems which are easier to use than auxiliary electrified inside anodes. An example of such a scheme for plating the interior of the deep recess in the bell end of a musical instrument is described in detail and suitably illustrated.

Wiring or block diagrams of the other control techniques discussed by the author are included in the paper.

Practical Aspects of the Atomizer Test, by Henry B. Linford and Edward B. Saubestre, Columbia University, New York, N. Y.

Although the atomizer test for the evaluation of degreasing processes is simple, the published directions for its use must be followed quite closely to obtain meaningful results. The specimen, which may be either a workpiece or a test sample, is dried completely and then sprayed for 30–45 sec. with water from a No. 251 DeVilbiss atomizer operated on compressed air at a pressure of 18 inches of mercury. The use of excessive spraying time, coarse sprays or other procedures which deviate from the recommended technique may lead to flooding of the specimen or other undesirable results. It is particularly important that the droplet size in the spray be sufficiently small that advantage can be taken of the sensitivity of wettability of an advancing contact angle between the water and the test surface.

Tests on the effectiveness of cleaners which are in operation should be made on actual workpieces if the

(*Continued on page 932*)

Book Review

DR. HAROLD J. READ
Professor of Metallurgy, Pennsylvania State College

EXHAUST HOODS by J. M. DallaValle, 2nd edition, 1952, vi + 146 pages. The Industrial Press, 148 Lafayette Street, New York 13, N. Y. Price, $3.50.

The new edition of this book contains so many changes and additions that it will be reviewed as a new book. This highly specialized monograph is an excellent example of pithy, clear and informative technical writing wherein the author adheres strictly to his principal subject matter and covers it with singular completeness.

The first four chapters are devoted to the theoretical and fundamental aspects of the problems relating to hood design. After a brief presentation of the general theory of the flow of gases into an opening, the special problems of velocity characteristics in structures of practical design for hood openings are considered. Considerable attention is given to criteria for determining the effectiveness of hoods. In these discussions mathematics is used sparingly, although the necessary formulas for design calculations are completely presented. Much use is made of graphical presentation, and significant data are given in tabular form.

The major portion of the volume treats of practical design for hoods to be used in a variety of situations and for various atmospheric contaminations such as dust, vapors, fumes, etc. Many actual examples are discussed and amongst these, metal finishers will find many which are directly or indirectly pertinent to their problems. Grinding hoods are discussed in considerable detail and there is a fair amount of material pertaining to exhaust problems in plating, degreasing and cleaning operations.

Chapters on examples of hood design calculations and hood entrance losses contain illustrations of the precise steps which must be taken to put into practice the principles of theory and design presented in the main portion of the text.

It may well be that engineers who use this book will be disappointed at the brevity of the chapter on actual hood construction. There is nothing here or elsewhere in the text on materials of construction, a subject which is particularly vexatious in the field of metal finishing, where the engineer must deal constantly with corrosive fumes.

The many line drawings and photographs amply illustrate the author's discussions and there is little which is not extremely pertinent to the text. Although the text is quite complete in itself, the author has provided references to additional literature at the ends of most of the chapters.

Convention Papers

(Continued from page 931)

pieces have some fairly smooth surfaces. If it is necessary to use test panels, they should be soiled artificially with oils or greases resembling production soils. The quantitative nature of the atomizer test enables an operator to follow exactly the loss in effectiveness of a cleaner, and he can replace or fortify the cleaner for complete effectiveness at minimum cost.

The precise scientific evaluation of cleaner formulations cannot be accomplished without a quantitative test for effectiveness. The simple, inexpensive atomizer test provides the tool needed in research and development work of this sort. Inasmuch as the test can be used in the shop as well as in the laboratory, a complete evaluation can easily be made.

When process changes prior to the cleaning operation lead to cleaning difficulties, it is often difficult, in the absence of quantitative data, for the plater to convince management that the changes may be undesirable so far as overall production is concerned. The atomizer test can provide figures to support the plater's plea for manufacturing process which will yield workpieces that he can clean at minimum cost.

Measurement of Adhesion

(Continued from page 864)

mitting the load to the interface that subjects the base metal and deposit to a stress state of high triaxial tension.

Previously proposed methods do not meet adequately these requirements. It has been demonstrated in the present work that it is possible to cause non-ductile fracture in annealed copper foil when the design of the test specimen is such that a triaxial state of tensile stress is obtained. The method may be adapted to the evaluation of the adhesion of electrodeposits in a manner which conforms to the aforesaid four principal requirements of a quantitative adhesion test.

Acknowledgment

H. C. Schlaupitz wishes to express sincere gratitude to R. Wallace & Sons Manufacturing Company, which sponsored this investigation. Appreciation is also expressed to Mr. William Whitty and Mr. Austin Norton of the Wallingford Steel Company for the use of its tensile machine. Acknowledgment is also due Dr. H. Leper of Yale University for a helpful discussion of the problem of measuring adhesion.

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TABLE III. EFFECT OF A SILVER STRIKE ON THE ADHESION OF A SILVER ELECTRODEPOSIT TO COPPER FOIL

Specimen	Silver Strike	Fracture Stress psi	Location of Fracture*
2a	Yes	48000	100% in copper foil
2b	Yes	42700	80% in copper foil, 20% in nickel nodule†
2c	Yes	36800	75% in copper foil, 25% in nickel nodule†
2d	Yes	13200	50% in copper foil, 50% in nickel nodule†
2e	Yes	3300	100% at nickel-silver interface
3a	No	30700	100% at nickel-silver interface
3b	No	24700	100% at silver-copper interface
3c	No	14700	50% at silver-copper interface, 50% in nickel nodule†
3d	No	9150	100% at silver-copper interface

*Per cent of fracture area estimated under low-power binocular microscope
†Failure of nickel nodules due to pitting

Nickel

(*Continued from page 927*)

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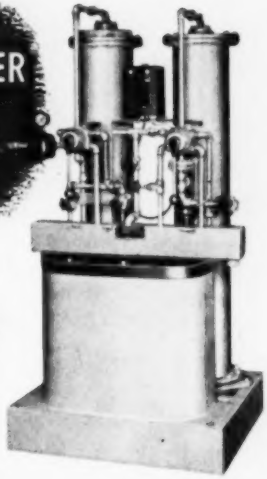

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(1) View of the crowd attending the opening session of the American Electroplaters' Society's 39th Annual Convention at the Conrad Hilton Hotel where Michael Di Salle, former director of the OPS, delivered the keynote address

(2) Chicago Branch President Raymond Ledford delivering welcoming address to the Convention

(3) Mrs. George Hogaboom selecting the tickets indicating the Convention "Queen" and her attendants

(4) "Convention Queen", Mrs. Mildred Zeitman of Pittsburgh, Pa., is crowned by A. P. Munning, of the Metal Finishing Suppliers' Association. Mrs. Evelyn Davis (left) and Mrs. Stanley Bever (right) were selected as the Queen's attendants

(5) James Zeder, Vice-President and Director of Chrysler Corporation (right), presents the first C. E. Heussner Award to Dr. Edward Parker of Technic, Inc., Providence, R. I., for his paper, "Electro plating of Gold Alloys"

(6) The International Fellowship Club Party in full swing

(7) Mrs. MacStaker, President MacStaker, George Wagner and their party enjoying the IFC festivities

(8) The buffet line at the IFC party

(9) Metal Finishing Suppliers' Association Luncheon

(10) Research Committee as photographed after breakfast at the Stock Yards Inn: Standing, left to right: R. Wysong, F. Ogburn, H. J. Weisner, Dr. E. Parker, J. Teres, L. Borchert, H. A. Kafarski, Dr. R. Schaefer, Dr. W. Blum, Dr. H. B. Linford; H. Smith, Dr. E. J. Serfass, W. J. Neill, R. A. Ehrhardt. Seated members, left to right: Dr. G. P. Swift, Dr. D. G. Foulke, C. Kelly, D. Price, W. L. Pinner, C. F. Nixon, R. W. Oyler

(11) New Research Committee members Vice-Chairman E. J. Serfass and R. Oyler with retiring Vice-Chairman W. L. Pinner

(12 and 13) H. J. Weisner and D. Milne presenting their papers during the first educational sessions

(14) Drs. Dodge, Linford and Serfass—speakers during the Research educational sessions

(15 and 16) F. Mesle and W. Phillips addressing the delegates and members upon their election to honorary membership

(17) New executive board for 1952–1953 after their election: C. F. Nixon, C. Kelly, Dr. R. A. Schaefer, Dr. G. P. Swift, F. J. MacStoker

(18) Michael Di Salle, former director of the OPS, cuts a metal plated ribbon opening the Industrial Finishing Exposition at Chicago's International Amphitheatre. Herb Head of Briggs Manufacturing Company (left) and Clyde Kelly, Exposition and Convention chairman (right), watch the ceremony as the crowd waits to attend the Show

(19) Herberth Head addressing the convention on aspects of the 3rd Industrial Finishing Exposition

(20) View of some of the exhibits in the International Amphitheatre

(21 and 22) Views of the Chicago Electroplater's Institute Exhibit at the Amphitheatre

(23) Wolfgang Heinrich and Dave Clarin relaxing during some of the Chicago heat

(24) E. L. Whitmore, Jr., of the Beaumont Plating Works, Texas, presents C. F. Robison with his priorities for nickel anodes

Convention Echoes II

The final registration figure for the Chicago Convention was reported by the Convention Committee to be 1,582 and the attendance at the Third Industrial Finishing Exposition was 11,000.

CONVENTION NEWS

Several changes in the A. E. S. By-Laws were made at the final business session. These are given herewith for the information of the members.

Interim Meeting. The Detroit Branch moved as follows and the motion passed:

WHEREAS: It is felt that much that is good for the American Electroplaters' Society will result from midyear meetings of the Supreme Society for the purpose of hearing reports and discussing A. E. S. problems, similar to the meeting called by President Nixon in Philadelphia on February 9, 1952; and

WHEREAS: It was the unanimous recommendation of the Delegates there assembled that a formal recognition of the privilege and responsibility of the President to call such meetings in the future be granted by the Supreme Society seated in regular Annual Meeting; therefore be it

MOVED: That the By-Laws of the Society be and hereby are amended as follows:

To Part I. Article VI. "MEETINGS AND CONVENTIONS", add the following Section: "*Section 9. Interim Meetings:* When it shall appear to be for the good of the Society the President shall, with the consent of the Executive Board, call an Interim meeting of the Supreme Society for the purpose of hearing reports and proposals, of considering all matters referred to it by the Annual Meeting, and of making recommendations to the Annual Meeting and the Executive Board concerning these and other matters which may come before it.

"Any such Interim Meeting shall be held at a time and place selected by the Executive Board."

Part I. Article II. *Section 2. President*, line 11, after the word "Special", insert the words "and Interim".

Part I. Article II. *Section 6. Executive Board*, line 28, strike out the sentence beginning "It shall approve . . ." and substitute: "It shall approve any call for a Special or Interim Meeting of the Supreme Society and shall designate the place and time of such meeting".

EDITORIAL BOARD

The following motion made by the Newark Branch passed. That the By-Laws, Part I, Article III (Committees) be amended as follows:

1. In Section 7 (Educational Committee) strike out the second paragraph.
2. At the end of the Article, after Section 10, add the following:
"*Section 11. Editorial Board:* The Editorial Board shall consist of ten members and the Executive Secretary, who in his capacity of Managing Editor of the official journal, shall be Chairman. One member shall be appointed by the Host Branch of each Annual Convention and shall hold office for the year terminating at that Convention. Of the nine remaining members, three shall be appointed each year by the Executive Board on nomination by the Editorial Board, and the term of each such member shall be three years or until his successor has been appointed and installed. No member shall be appointed for consecutive three-year terms.
"The Editorial Board shall be responsible for the Educational Sessions at Annual Conventions and shall assist the Managing Editor of the official journal in the determination of policy and the procurement of material".

RESEARCH FUND

A sense-of-the-meeting vote was requested by the Chicago Branch on the proposition that the Society increase its minimum dues by the sum of one dollar, said dollar to be paid into the Research Fund. The Supreme Society voted favorably on the motion which will be published in proper form in PLATING as required by the Constitution before this constitutional change can be voted upon by the Delegates.

HEUSSNER AWARD

The action of the Executive Board in establishing the Carl E. Heussner award was supported by the Supreme Society which adopted the following resolution presented by the 1952 Paper Awards Committee.

WHEREAS: An endowed award has been offered to and accepted by the Executive Board of the A. E. S. to be known as the Carl E. Heussner Award; be it hereby resolved that the Appendix to the By-Laws titled "Paper Awards", Paragraph 2 (a), be deleted and the following substituted therefor: "The Carl E. Heussner Award, consisting of the A. E. S. Gold Medal, fifty dollars and an award certificate, for the best paper printed in Society publications during the fiscal year".

In this connection the following resolution was also approved:

WHEREAS: the services and achievements of our old friend and companion, Carl E. Heussner, now fresh in our minds, have been preserved for the benefit of those who follow us, through the establishment under his name of a worthy Award for achievement in his chosen field, be it therefore

RESOLVED: that this Society hereby acknowledge to Glenn Fried, generous donor of this award, its obligation for his open hand and its appreciation of the fitting character of his gift.

The services of Gustaf Soderberg to the Society were recognized with the approval of the following resolution:

WHEREAS: on May the Sixteenth of this year the great nation of Sweden, land of giants physical and intellectual, foreclosed the mortgage and called the note under the generous terms of which we here have prospered for three decades past; and

WHEREAS, as a result of this action

GUSTAF SODERBERG

has departed from these shores and from the bosom of this Society to restore to his native land the prestige of his personality, the effulgence of his wisdom, and the benefits of his teaching; and

WHEREAS, in his activity as member, lecturer, and editor Gus has enriched our experience, enhanced our skill, and added beyond measure to our store of happy memories; be it then

RESOLVED: that American Electroplaters' Society extends to our old friend Gus sincere acknowledgment of his devotion to the welfare of the Society, deep admiration for the success which has met his efforts, and the affectionate certainty that fruitful years will bring him the the recognition, the friends, and the satisfactions which he completely deserves.

The Delegates also expressed the appreciation of the Society to all those whose efforts had made the Chicago Convention and the Metal Finishing Exposition a success by approving the resolution:

WHEREAS: The American Electroplaters' Society has for this summer interlude basked in the mild and friendly rays of Chicago's sympathetic sun, sampled Lake Michigan's exhilarating breezes, and expanded under the active hospitality of the great Midwest; and

WHEREAS: we have absorbed the benefits of, first, an educational program consummately adapted to the exactions of these difficult times; and, second, a brilliant refresher course in equipment methods at the Industrial Finishing Exposition; be it then

RESOLVED: that the names of all Convention Committee Members be inscribed on the Proceedings of this session; and that the Society thanks them and all who participated in this Convention in America's leading summer resort, including especially the following:

President Ledford and Chicago Branch, gracious and indefatigable hosts;

Bill Geissman and Lenny Weeg and Rockford Branch, Harold Wiesner and Ralph Wysong and St. Joseph Valley, and the inspiration that enlisted them in this happy collaboration;

Mrs. Longfield and the Ladies' Committee, who have kept our better halves happily occupied and left us uninhibited for attack on our serious problems;

Clyde Kelly, Marion Longfield, and the administrative committees whose good judgment and hard work have made smooth sailing of an intricate course;

Herb Head, ringer from Detroit, whose organizing genius is the best insurance for any exposition, and the shirt-sleeved boys who have sweated with him among the perfumes of Araby;

H. W. Gilbertson, master plater and Nestor of the Chicago Branch;

Joe Andrus, brilliant addition to the Editorial Board, and his Educational Committee; their fertility of resource is reflected in the success of the technical sessions;

Gus Munning and the Metal Finishing Suppliers for the International Fellowship Open House, Hanson-Van Winkle Munning Company for their efficient circulation of our daily news, Dave Clarin and Oakite for keeping Aunt Ella in full and blooming health, and Joan Wiarda for conducting the Plato Party in its best tradition;

Most especially the inevitable few whom this resolution has regrettably overlooked; and finally

Our honorable officers and our memorable selves, for being here; and the City of Brotherly Love for its assurance that, come another June, we shall have another occasion for thanks from grateful hearts.

PAPER AWARDS

The Certificate of Honorable Mention was granted for the paper, "Operating Control for Optimum Plating Characteristics", authored by R. O. Hull and J. B. Winters. The Chromium Plating Award, sponsored by the Nutmeg Chrome Corporation, was granted for the paper by E. W. Neben and W. F. Swanton on "Recovery of Chromic Acid from Plating Rinse Waters". No grants were made of the Mechanical Finishing Award sponsored by the Lea Manufacturing Company, and the Gold and Gold Alloy Plating Award sponsored by Technic, Inc.

CONVENTION NEWS

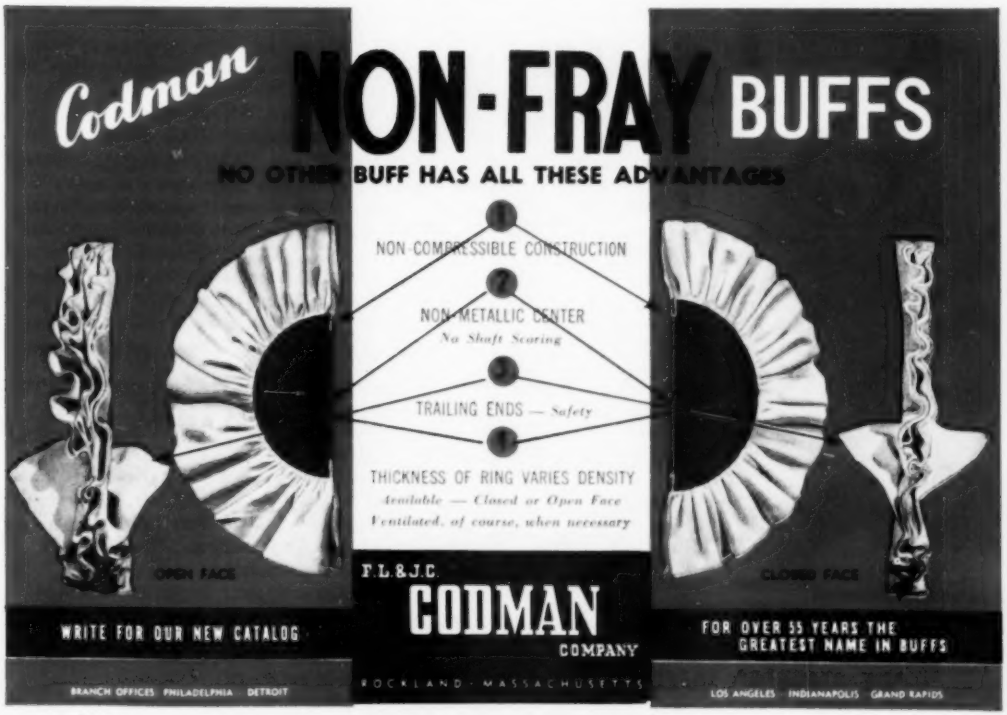
Mr. Joe Duffy has reported the winners of the Metal Finishing Suppliers Association Golf Tournament as follows:

Low Gross—79, Jim Badaluco
Low Net—70, Fred Edwards
2nd Low Net—71, Oscar Kuntz
3rd Low Net—72, Mike Borushko

Other reports that have come to us have noted prize winners of the various drawings in Chicago. Knowing the members who attended, as well as those who were unable to do so, are interested in the names of the lucky ones we report that the contest sponsored by the Kaynide Division of the Kraft Chemical Company at the Exposition was won by Sigmund M. Anzarek, Chicago, Ill. (Holliwood Broiler); L. Hartman, Owosso, Michigan (Proctor Automatic Toaster); Mrs. Rex Oyler, Anderson, Ind. (G. E. Steam Iron and Water Boy); and E. H. McCoy, Chicago, Ill. (Sunbeam Shavemaster).

The laminated fiberglass boat in the contest sponsored by MacDermid, Inc., was won by Bob Plaisted of Stamford, Conn.

The winners of the Hanson-Van Winkle-Munning sponsored drawings are announced as follows: Mike Kanter, Passaic, N. J. (Silver Service); Mrs. Albert C. Barth, St. Louis, Mo. (Sunbeam Mixmaster), and Edna Heavens, Detroit, Mich. (Sunbeam Coffeemaster).



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Article Abstracts

No copies of articles are available at the offices of "Plating". Photostats may be had from libraries having files of the journal in question and offering photostat service, usually at 30-50 cents a page. Ask your public library to consult the Union List for names of libraries having the particular journal. Abbreviations used are those of Chemical Abstracts.

LYMAN B. SPERRY

The Physical and Chemical Changes which Accompany the Polishing of Metals. A. J. W. Moore, PhD. J. Electrodepositors' Tech. Soc., **28** (1952).

All mechanical methods of smoothing metals (grinding, burnishing, buffing, lapping, etc.) involve sliding between the metal surface and the polishing agent. It has been shown that the actual area of contact is only at the high points; for instance, two steel flats had an actual contact area only 0.0001 of the apparent contact area. When surfaces are slid across one another, extremely high temperatures (800° C) may be developed at the points of actual contact, and melting of the lower melting substance may occur. Particles of one metal may be welded to another, and the weld may be stronger than the tensile strength of the metals, so that particles may be torn out and subsequently re-embedded. It is concluded that abrasives are primarily substances of high melting-point which can cause local high temperatures and hence surface flow of asperities.

Practical Considerations in the Application of Vacuum Coating for Metal Finishing. L. Holland. J. Electrodepositors' Tech. Soc. **28** (1952).

For this process, high-speed vacuum pumps developing a vacuum of 10^{-4} mm. Hg are necessary. To obtain a mirror-like deposit, it is unnecessary to polish the receiving base to this degree of surface smoothness; instead, the surface is first coated with a lacquer and the metal is applied over this. Aluminum is the metal most useful for deposition, because of its high reflectivity and tarnish resistance. The paper discusses the design of tungsten filaments for evaporating aluminum, methods of preventing granular films, better adhesion

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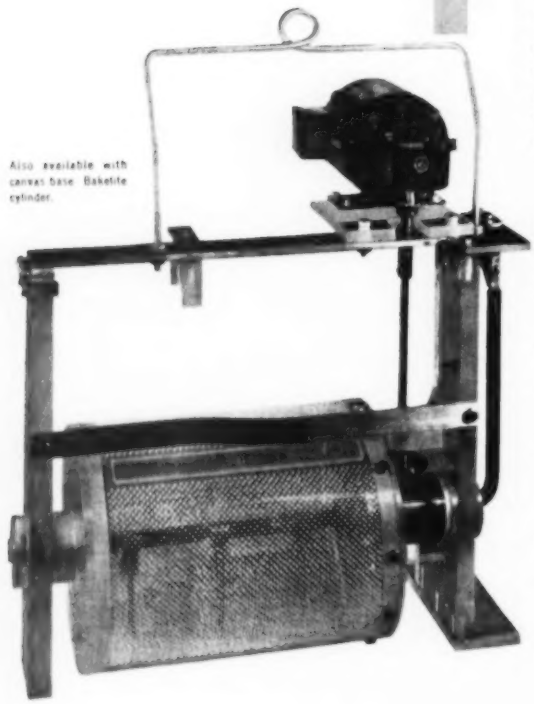

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produced by preliminary glow-discharge bombardment, and the effects of contaminating vapors. The reflectivity of evaporated aluminum films is compared with that of evaporated silver films. Graphs, sketches, and photographs are presented.

Lacquering to Obtain Brilliance and Metallic Lustre. H. H. Vevers and G. E. Gardam. J. Electrodepositors' Tech. Soc. **28** (1952).

In the finishing of costume jewelry and allied products, one method used is to lacquer, deposit metal by the vacuum evaporation process, lacquer, and finally develop color by immersing in a spirit stain for such a time that the stain does not diffuse through the lacquer. Uniform color may be obtained by this method. This paper describes experimental work done to determine the smoothing power of different lacquers. The base lacquer determines the success or otherwise of the process, and must have six specific properties, which are listed. Top lacquers are considered to be less exacting, but still important for success. Five important characteristics necessary to a good top lacquer are listed. Methods of application of lacquers, and their "stoving" (baking) are discussed.

Inspection of Electroplated Aircraft Parts. P. Skeggs. J. Electrodepositors' Tech. Soc. **28**, 15–26 (1952).

The general policy of the British Aeronautical Inspection Directorate in inspecting plating for aircraft parts is outlined. Sampling, pre-plating inspection, visual inspection after plating, thickness testing, porosity testing, hardness testing, and other requirements for certain plated metals are dealt with. The measurement of the thickness of thin films by radiation backscattering has been applied to electroplated coatings, and is said to be highly sensitive and accurate. "One American claim is that the thickness of tin plating is measured to an accuracy of 10^{-6} in., despite 'substantial variations' in the thickness of the basis steel". The method is explained, and a sketch of the apparatus and three graphs are given.

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Patent Abstracts

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Consultant, New Britain, Conn.

Copies of patents may be obtained by writing to Commissioner of Patents, Washington 25, D.C. Price 25 cents each.

No. 2,592,614, April 15, 1952—Method of Making Tubular Metallic Wave Guides—W. B. Stoddard, Jr., assignor to The Champion Paper and Fibre Company.

CLAIM 1. Method of making tubular metallic wave guides which comprises: forming a fusible metallic core; treating the core in a solution characterized by the presence of an acid radical containing a metal chosen from the class consisting of vanadium, chromium, molybdenum and tungsten; electrolytically forming thereover a layer of copper; electrodepositing thereover a layer of silver; electrodepositing a layer of nickel over said silver layer; fusing the core *in situ* and removing the core metal; cleaning out residual core metal; and thereafter chemically dissolving the copper layer in a strongly ammoniacal solution of divalent copper to leave the inner surface of the wave guide clean and smooth.

NOTE: Fusible alloy: Bismuth, 50 per cent; Lead, 35 per cent; Tin, 9 per cent; Cadmium, 6 per cent.

13 claims, 8 figures, 2 examples.

References cited: U.S. Patents 602,212; 850,912; 898,404; 1,011,603; 1,412,174; 1,674,941; 2,001,998; 2,004,102; 2,365,959; 2,381,367; 2,451,341. British Patent 230,456. Metal Ind. (London) **49**, 239–241 (September 4, 1936).

No. 2,592,810, April 15, 1952—Method of Electrolytically Processing Metallic Articles—J. B. Kushner.

CLAIM 1. A method of electroplating an object in a nonconductive tube which is open at each end thereof and which is closed intermediate save at a lateral inlet of said tube which is located intermediate said open ends, which consists in moving said object unidirectionally into said tube through one of said ends

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Saving the cost of converting the tank is not the only benefit. The Unichrome Copper Process maintains a wide plating current range, and without brighteners, deposits a smooth plate excellent for direct plating with chromium. It contains no cyanide to dispose of. Bulletin CU-2 gives more data.

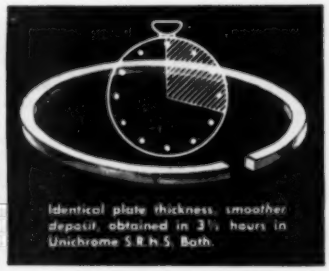
EFFICIENT INSULATION ASSURES MORE EFFICIENT PLATING

Use of proper insulations not only improve plating results but also saves current and metals. Unichrome Stop-Off Compounds and Lacquers are noted for ease and economy of application on the work to be plated; Unichrome Coating 218X for the long lasting protection it gives to racks despite the toughest plating and cleaning cycles.

Tantalum Coils Last and Last

Installing a Unichrome Heating Coil or Heat Exchanger with tantalum tubes is good economy. Giving trouble-free service in acid baths for remarkable periods of time, the tantalum virtually eliminates maintenance, downtime and loss of valuable plating production. At one plant, a tantalum coil has already seen 4 years of service and is still as good as the day installed.

Piston rings plated to thickness specifications in ordinary chromium bath took 5 hours.



Identical plate thickness, smoother deposit, obtained in 3½ hours in Unichrome S.R.H.S. Bath.

■ There's a big difference in the hard chromium plating operations of many plants nowadays. It has been simplified, speeded up, and consistently better results assured – all through installation of the Unichrome S.R.H.S. Chromium Bath. The improvements reveal themselves in many ways.

A REAL GAIN IN OUTPUT

Especially in hard chromium plating, where it often takes many hours to deposit the specified thickness of chromium, the higher plating speed of S.R.H.S. Chromium works wonders. Cutting plating time by 20 to 50%, it helps to boost production without extra equipment. For example, piston ring plating takes 3½ hours now, instead of the 5 it used to at one plant. Another plant plates .005" of chromium on steel bushings in 2½ to 3 hours – half the usual time – by using a Unichrome S.R.H.S. Chromium Bath. And the deposit is smoother, too.

MANY PRODUCTION ADVANTAGES

Unichrome S.R.H.S. Chromium Solution deposits chromium with less "treeing". Its "leveling action" also assures a smoother plate. Both these features mean less need to deposit excess chromium to allow for grinding and final finishing – thereby saving additional plating and production time.

As a self-regulating bath, Unichrome S.R.H.S. Chromium not only minimizes control problems, but also maintains top throwing power and reduces rejects.

LOSS OF FATIGUE STRENGTH MINIMIZED

Chromium plating is known to reduce fatigue strength of steel. Recent research has proved, however, that parts plated in the Unichrome S.R.H.S. Chromium Bath have the smallest loss of fatigue strength. Here are some results on heat-treated test specimens plated with 0.001" of chromium as reported by an independent laboratory:

Chromium Plating Solution	Fatigue Strength psi	% Loss Over Unplated
Unplated	81,500	—
Ordinary	60,500	25.7
SRHS CR-100	75,200	7.7
SRHS CR-110	75,300	7.6

* * *

Write or phone the nearest United Chromium office for more information on getting better chromium plate for defense or industrial applications. Electroplating engineers will be glad to show you how you can meet specifications in less time and with less trouble by means of the S.R.H.S. Chromium Bath.

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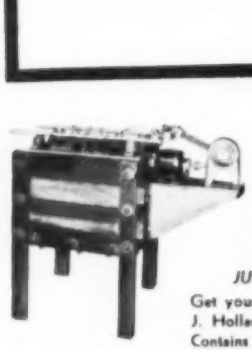

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Patent Abstracts

and through said tube and out of said tube through the other of said ends, connecting said object during said movement to the negative terminal of a source of unidirectional current, forcing liquid electrolyte laterally into said tube at said lateral inlet to strike said object laterally at said inlet, said liquid electrolyte being thus formed laterally into said tube at said inlet at sufficient lateral velocity to strike the part of the closed wall of said tube which is aligned laterally with said inlet and to change abruptly the direction of said laterally forced liquid electrolyte and to produce a zone of turbulence at said inlet and said part of said closed wall, said lateral velocity being sufficient to fill said tube and to produce respective streams of electrolyte which flow in respective opposed directions in turbulent flow away from said lateral inlet towards and out of said open ends, and passing unidirectional plating current from the positive terminal of said source through anode means and said electrolyte, said anode means being at least partially located in said zone of turbulence.

7 claims, 5 figures.

References cited: U. S. Patents 1,068,411; 1,068,412; 1,117,240; 1,601,690; 1,927,162; 2,075,331; 2,108,978; 2,171,437; 2,206,908; 2,222,839; 2,244,423; 2,349,908; 2,370,973; 2,392,687; 2,395,437; 2,407,145. German Patent, 630,041. "Belke Insulated Racks", Bulletin No. 800, Belke Manufacturing Company, Chicago, Ill.

No. 2,594,820, April 29, 1952—Process for Manufacturing Timepiece Dials—C. Stern, Geneva, Switzerland.

CLAIM 1. A process for manufacturing timepiece dials, comprising the steps of stamping indicia members in relief on a plate of light metal of the group consisting of aluminum and magnesium and their alloys, anodizing the plate to produce a non-conducting oxide coating thereon, abrading the upper surface of the prominent indicia members to remove the oxide coating therefrom, thereby making only the surface of said indicia members electro-conductive, and electroplating said electro-conductive indicia members while

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Patent Abstracts

the background of the plate is preserved by the oxide coating.

CLAIM 2. Electroplating as in Claim 1, and dyeing said dial subsequent to formation of said oxide coating.

CLAIM 3. Anodizing the plate to produce a non-conducting oxide coating thereon and simultaneously dyeing said dial.

3 claims, 5 figures.

References cited: U. S. Patents 864,467; 1,373,430; 1,722,778; 2,085,988; 2,233,410; 2,237,483; 2,324,106; 2,430,468. Switzerland 65,167; 113,396.

No. 2,598,486, May 27, 1952—Electrolytic Tin Plating Baths—John W. Andrews, assignor to United States Steel Corporation

EXAMPLE I

An aqueous solution containing the following ingredients:

	Grams/liter
Phenolsulfonic acid	130
Tin	35
Total sulfate radical	35
Toluidine	3
Formaldehyde sufficient to form a ratio of 3 mols of toluidine	

At operating temperatures of about 90° F to 110° F and a strip speed of 100 feet per minute, this bath deposited coatings having satisfactory brightness or luster, ductility and coherence within a current density range of about 100 to 175 amperes per square foot. At the same temperature and a strip speed of 250 feet per minute the current density range for similarly satisfactory coatings was about 150 to 500 amperes per square foot.

CLAIM 1. An electrolytic tin plating bath consisting of an aqueous acid solution of 10 to 80 grams per liter of tin in the form of a stannous salt of an acid of the group consisting of phenolsulfonic acid, benzene meta-disulfonic acid and sulfuric acid, and the reaction product formed by dissolving an amine in said solution

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1— 1500 A. HVW 6-12 V.	1— 800 A. G. E. 28 V.
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1— 150 A. HVW 6 V.	1—1000 A. Chandey 40 V.
3— 125 A. Hobart 6 V.	1—1950 A. Cent. 45 V.
1— 120 A. Eager 7½, 15 V.	1— 75 A. G. E. 50 V.
1— 100 A. HVW 6 V.	1— 325 A. West. 50 V.
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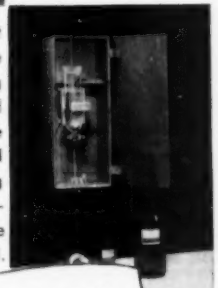
● The KOCOUR automatic dropping unit is electrically operated . . . is invaluable for rapidly checking the thickness of plated deposits . . . the set is designed to deliver at the proper dropping rate and to time the interval it is in operation. . . . This eliminates the need of any other timing device. . . Overplating and underplating are both expensive since one wastes time and material and the other leads to rejects.

Comes compactly assembled in a well made cabinet . . . easily mounted on a wall or upright, convenient to a 110 volt, 60 cycle, A.C. electric outlet.

● The manually operated set uses the same solutions as the automatic set but the dropping rate must be adjusted by hand and a timing device must be used. . . The principles involved are the same—that of dropping a corrosive solution at a definite rate onto a plated article until the base metal is exposed.



● KOCOUR testing sets are used all over the world for controlling plating — cleaning — pickling — anodizing — and hardening processes . . . special sets can be provided for your requirements.
Write today for complete information — no cost or obligation.

KOCOUR COMPANY
4801 S. ST. LOUIS AVENUE
CHICAGO 32, ILLINOIS

Specify KOCOUR test sets from your supplier

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FLAME-SPRAYED CORROSION-RESISTANT POLYETHYLENE-LINED DRUMS

Better - Yet Costs Less!

Seamless *Standard*

Platers are enthusiastic about these new corrosion-resistant drums for operations where they formerly used breakable glassware and crocks . . . dipping, storing, plating, filtering, etc. . . . for practically any chemical used in the plant!

Schorithene is a seamless plastic lining made of polyethylene powder with the patented Schori Flame-Spray Pistol . . . the most corrosion-resistant material available today. Bonds firmly to metals, assuring long life; easy to clean. Drums coated on outside with plastic paint as protection against splash and drip.

Order Schorithene-lined drums directly from us or your distributor. See price list. Prices F.O.B. Long Island City; orders accepted from rated companies, otherwise payment with order. No COD's.

PRICE LIST

Gallon Cap.	Inside Diam.	Inside Height	List Cost
	STANDARD		
3½	11″	9″	$7.50
5	11″	12″	9.50
15	15″	20″	17.50
20	18″	20″	24.50
30	18″	27″	29.50
55	22″	34″	36.50
	SEAMLESS		
30	18″	27″	40.00
50	22″	34″	52.00

Covers $4.00 extra

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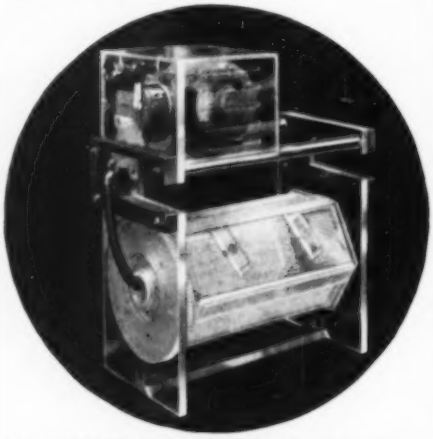

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for HARD CHROMIUM

USE Zialite ADDITION AGENTS

Harder deposits.
Increased throwing power.
Less sensitivity to sulfate content.

Exceptionally fine results plating anything calling for Decorative or Hard Chrome.

for NICKEL PLATING

The one bath especially designed for plating DIRECTLY on ZINC, LEAD ALUMINUM, BRASS, COPPER and IRON.

ZIALITE CORPORATION

92 Grove Street Worcester 5, Mass.

Patent Abstracts

and gradually adding formaldehyde thereto at a temperature of 40° to 60° C, the amine being present in a concentration of 2 to 6 grams per liter and being of the group consisting of aniline, toluidine, xylidine and chloraniline, the formaldehyde being present in an amount of 1 to 3 mols of formaldehyde per mol of amine, said solution having a total free acid content expressed as the H_2SO_4 equivalent of 20 to 50 grams per liter.

12 claims, 8 examples.

References cited: U. S. Patents 1,987,749; 2,450,795.

No. 2,600,352, June 10, 1952—Bright Zinc Electroplating—Christian J. Wernlund, assignor to E. I. duPont de Nemours & Company.

Aqueous zinc cyanide electroplating solutions were prepared having the following compositions:

$Zn(CN)_2$	60 g/l
NaCN	50–60 g/l
NaOH	75 g/l
Na_2S	0.5 g/l
$Na_2SnO_3 \cdot 3H_2O$	1.5 g/l

In a series of electroplating operations, utilizing electrolytes of the above composition, with the further addition in each case of a ketone, sheet steel electrodes were electroplated with zinc at current densities of 2 to 90 amp/sq ft and at a bath temperature of 25° to 30° C.

Claim 1. The process which comprises electroplating zinc from an aqueous zinc cyanide solution which contains about 60 grams per liter of zinc cyanide and an alkali metal stannate in the amount equivalent to 1 to 2.5 grams per liter of sodium stannate and to which has been added about 3 to 26 grams per liter of a ketone selected from the group consisting of acetone, methylethyl ketone, methyl *n*-propyl ketone, gammahydroxypropyl methyl ketone, acetyl acetone, diacetone alcohol, mesityl oxide and cyclopropyl methyl ketone.

4 claims, 4 examples.

References cited: U. S. Patents 736,565; 1,904,732; 1,905,105; 2,109,887. Great Britain 482,958; 548,009.

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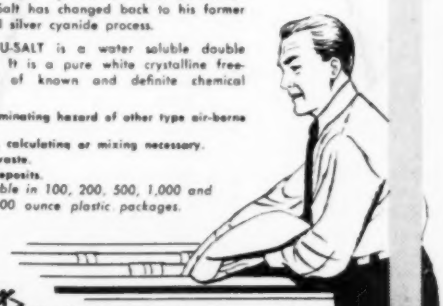

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Produces mirror-like deposits regardless of thickness, without any need for scratch brushing or buffing. (No loss of gold.)

100% cathode efficiency permits easy calculations for cost and specification plating.

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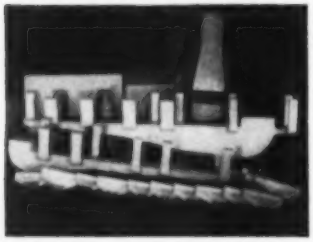
FAMOUS AVIATION COMPANY EQUIPS NEW PLANT WITH COMPLETE EXHAUST SYSTEM RESISTANT TO CORROSIVE FUMES



PLA-TANK®

RESIN-BONDED FIBERGLAS®

PLATING TANKS INCLUDED

Process tanks for plating solutions and passivating dips were included in this large order placed by a well-known aviation company for installation in their new plant. This picture shows only the Exhaust Hoods complete with Ducts for the down draft exhaust system which was connected to the tanks.

All of the parts were fabricated from PLA-TANK — with some of the tanks and fittings right out of stock. PLA-TANK is a corrosion resistant material, made of Fiberglas, impregnated and bonded with polyester resins. It is molded into strong units, light in weight but extremely durable. It is resistant at temperatures from −60°F. to +280°F.— does not soften under high heat. Moreover, it's not just a lining but equally resistant inside and out.

You'll find PLA-TANK ideal for your plating room use. Many sizes in stock for immediate shipment — special sizes made to order. PLA-TANK also makes a perfect lining for steel tanks. Supplied in sections, it is welded in place on the job to make one strong, sturdy unit.

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THE Chemical CORPORATION

37 Waltham Ave., Springfield 9, Mass.

A. E. S News

Two New Branches

At the Executive Board meeting held Sunday of convention week the request of the Kansas City Branch and the Wichita Branch for temporary charters was granted. The Kansas City Branch with 34 members and the Wichita Branch with 19 members and one in-transfer as of record at Headquarters indicate that these are two healthy Branches which will grow in stature.

Philadelphia Convention Papers

At a meeting of the Editorial Board held at the Stock Yards Inn during the convention, plans were laid for the Educational Sessions at the Philadelphia Convention. Past President Fred Fulforth, Educational Chairman, reported one paper promised and additional offers have come in. It is requested that all those planning to present papers at the 1953 Convention submit a summary promptly either to the Executive Secretary or any member of the Editorial Board so that careful consideration may be given each paper.

Industrial Finishing Exposition

At the final Business Session of the Supreme Society held June 19, 1952 it was voted to hold the 1955 Convention in Cleveland. At that time the question of whether or not an Industrial Finishing Exposition should be held in conjunction with this convention was turned back to the Executive Board for decision. Because of the need to take up an option on Convention Hall in Cleveland in early July, the Board voted in meeting June 20 to hold an Exposition in Cleveland in 1955. At the same time a policy minute was adopted to the effect that trade shows at intervals of three to four years are a good thing for the industry as a whole and for the Society.

New Sustaining Members

The number of companies supporting the A. E. S. Research Program continues to increase. We welcome the following who have become Sustaining Members since our last report:

American Anodizing & Plating Co., Chicago, Ill.
Cutler-Hammer Co., Milwaukee, Wis.
Electro-Platers Co., Milwaukee, Wis.
Fox Products Co., Philadelphia, Pa.
Knapp-Monarch Co., St. Louis, Mo.
Milwaukee Plating Co., Milwaukee, Wis.
F. D. Pace Co., Grand Rapids, Mich.
Sommers Bros. Mfg. Co., St. Louis, Mo.
R. Wallace & Sons Mfg. Co., Wallingford, Conn.

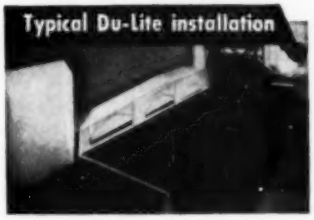
On any steel blackening problem

DEPEND on DU-LITE for a Superior Finish

Courtesy The Poly Choke Co.

Du-Lite gave this part with its complicated knurls, slots, threads, etc. a fine rust-resistant durable black finish. It is typical of many other parts, small and large, which have been black oxidized by Du-Lite for many years. Moreover, Du-Lite meets most individual and government specifications including 57-0-2C for Type III Black Oxide finish.

Typical Du-Lite installation



Du-Lite installations are simple, compact, easy to operate. Du-Lite equipment can be tailored to fit production requirements on all types of jobs with a maximum of speed and economy. Du-Lite also makes a complete line of cleaners, strippers, wetting agents, passivating agents, rust preventatives, burnishing compounds etc. for any metal finishing application.

See your nearest Du-Lite Field Engineer or write for more information.

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MIDDLETOWN, CONN.

Rush information on your metal finishing products.

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Company
Address
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METAL FINISHING SPECIALISTS

USE "RELIANCE" PRODUCTS FOR

ECONOMY : EFFICIENCY : DEPENDABILITY

LET US SUPPLY YOUR NEEDS FOR YOUR PLATING OR POLISHING DEPARTMENT

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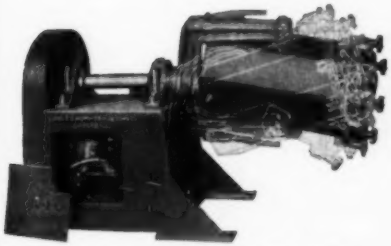
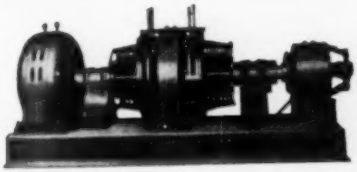
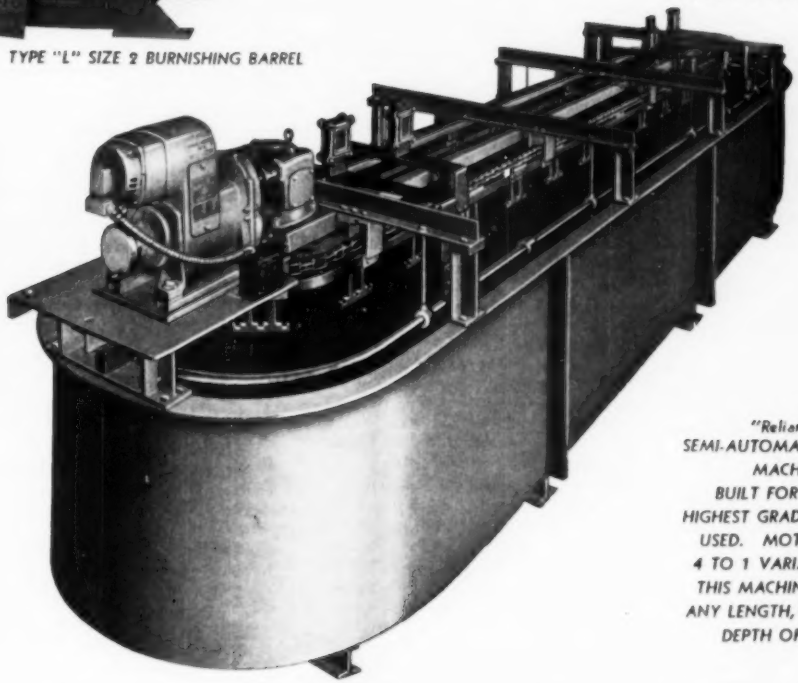


TYPE "L" SIZE 2 BURNISHING BARREL



3000 AMP. 6 VOLT GENERATOR SET



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SEMI-AUTOMATIC PLATING MACHINE
BUILT FOR SERVICE
HIGHEST GRADE MATERIAL USED. MOTOR ½ HP
4 TO 1 VARIABLE SPEED.
THIS MACHINE IS BUILT ANY LENGTH, WIDTH AND DEPTH OF TANK.

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FOR FURTHER INFORMATION, USE READER SERVICE CARD; INDICATE A 1069.

Branch News

ALLENTOWN-READING BRANCH

Allentown-Reading Branch reports elections for the fiscal year 1952–1953 as follows:

President—James F. Riegel
First Vice-President—Joseph McKeone
Second Vice-President—L. George Nissen
Secretary-Treasurer—Lee C. Wotring
Librarian—Howard Schearer
Board of Managers—Carl J. Swartz, G. Larry McMichael, Louis Siessmayer

Pearl T. Treisback, *Secretary*

CHICAGO BRANCH

One hundred Chicago members turned out for the May 9th branch meeting to hear Mr. C. F. Paulson of The Permutit Company discuss recovery of profitable wastes from plating operations using ion exchange equipment. Mr. Paulson illustrated his address with a fine selection of slides demonstrating in detail advantages of this recovery technique. Following his presentation, a lively question and answer period was conducted for the benefit of those attending.

"They Were There" Department

A pleasure to see Fred Schneider and Fred Zavasnik from Crane Company in attendance. Fred Schneider has been under doctor's orders for quite a while . . . Frank Lavitas finally made it from Florida . . . Lee Seabright of Acme Steel in attendance . . . "Old Reliable" Pete Belson sharing his plating experience with some of the younger members . . . Bill Jefferies of DuPont telling his troubles to Mary Daniels and P. C. Miller . . . John Kurdenock brought news of his new association with American Rack Company . . . Harry Schuessler and Vic Brouse of Apollo Metal Works turned out to learn about ion exchange . . . Art LaTour and S. Rickert discussing mutual problems . . . new members Dallas Armstrong, Mike Nakashima, Ralph Belke, Charlie Norcross and Floyd Mickelson getting into the regular attendance habit . . . Rudy Hazucha will certainly appear on the list of America's best dressed men . . . Frank Swagler of A. B. Dick made his appearance . . . Joe Andrus brought C. M. Iwen along . . . The Kocour brothers out in force, Cyril, Les and Orv.

Edward Stanek, *Secretary*

CINCINNATI BRANCH

The Cincinnati Branch of the American Electroplaters' Society made its annual inspection trip on April 30th when forty-two members made the pilgrimage to Dayton where they were the guests of the Frigidaire Division, GMC. They were rewarded with a strenuous but enlightening tour of some 130 acres of the vast Frigidaire plant where they saw the stamping, welding, fabricating, assembling, plating and finishing of the many parts used in the manufacture of refrigerators, electric ranges, freezers, water heaters and other products produced at this plant.

The last regular meeting of the season was held on May 28 at the Engineering Society headquarters. The proceedings were opened with a movie presented by Minnesota Mining & Manufacturing Company on the polishing of jet engine blades. A short talk on belt polishing was then given by Orville Hitzeman of the local office. President R. D. Miller then opened the business portion of the meeting with Secretary Wise reading a letter of resignation from G. Walda Parke who has been transferred to Cleveland. The resignation was reluctantly accepted, and then the applications of Earl Leonhardt and Curtis Varland were unanimously accepted. Charles Wise suggested that the Cincinnati Branch conduct a regional meeting in the fall such as held in Indianapolis and Dayton. Mr. Wise was appointed chairman of a Committee consisting of Messrs. Bonem, Stephenson and Gannon to investigate possibilities of holding such a meeting.

Mr. James W. Hensley of Wyandotte Chemical Corporation was introduced as our speaker, and discussed "Radioactive Tracers in Metal Cleaning", pointing out that they were mainly used in laboratory work but expressed the hope that some day such tracers could be used in the shop.

The Minnesota Mining & Manufacturing Company were hosts for the social hour which concluded the evening.

Charles Wise, *Secretary*

CINCINNATI BRANCH

The Cincinnati Branch of the American Electroplaters' Society concluded a highly successful season on June 7, with their annual Stag Picnic at Devou Country Club, Covington, Ky. Unfortunately, Greater Cincinnati was "enjoying" one of those typically humid days for which the Queen City has gained a not very enviable reputation. As a result any activity requiring physical exertion was at a minimum. A few of the hardier (but not necessarily the smartest) souls shot a minimum of nine holes of golf, and then were ready either for a shower and/or the undertaker. Of course, there was a little baseball but very little since the fortunate presence of free beer more or less interfered with any serious playing of the national pastime.

So card-playing, convivial conversation, and a bounteous roast beef dinner were indulged in by the majority of those present, all of whom agreed unanimously that Members Ray Barry and Stewart Chipman did a thoroughly good job o planning and executing the 1952 picnic

Charles Wise, *Secretary*

CLEVELAND BRANCH

The Cleveland Branch reports the elections of the following for the fiscal year 1952–1953:

President—Harry Pochapsky
First Vice-President—J. D. Little
Second Vice-President—W. G. Cryderman
Secretary-Treasurer—A. J. Lupien
Librarian—Henry R. Friedberg
Assistant Librarian—Justin N. Emlich
Board of Managers—E. C. Friedl, L. N. Elicker, Howard H. Blouch

A. J. Lupien, *Secretary*

DALLAS-FORT WORTH BRANCH

Dallas-Fort Worth Branch held its regular monthly meeting March 19 at the Lennox Hotel, in Grand Prairie, Texas.

The following members were nominated and elected for the ensuing year:

President—C. P. Lavelle
First Vice-President—John H. Oneal
Second Vice-President—John A. Laphan
Secretary-Treasurer—A. C. Fricke
Librarian—Robert H. Heppel
Board of Managers—Frank Lane, Cecil White, Kurt W. Kirsten

After the business meeting had been concluded Mr. Kenneth P. Bellinger, Executive Vice-President of the Chemical Corporation, Springfield, Mass., spoke on the subject of "Zinc Coatings".

Thirty-nine members and three visitors were in attendance.

A. C. Fricke, *Secretary*

GRAND RAPIDS BRANCH

The Grand Rapids Branch takes pride in announcing that for its first meeting of the season, on Friday evening, September 12, Mr. Earl M. DeNoon, owner and operator of South Florida Test Service, will tell us about testing in southern Florida. His subject title is "Tomorrow's Products Tested Today", and will cover the testing of not only plating, but also other protecting coatings, plastics, rubber, textiles, metals, and related materials. In more detail, he will describe, by use of

"Hey! Those are not for the birds!"

NOW SHOWING
ALL STAR CAST
of NEW
AHCO DEVELOPMENTS
. . . FOR BETTER METAL FINISHING

AHCO STAINLESS STEEL BUFFING COMPOUND
All abrasive types and grades. For cutting down and coloring stainless steel. Formulated to meet your specific requirements. Write for Bulletin B-1.

AHCO GREASELESS COMPOUND
For polishing and cutting down metals, woods, and plastics . . . for brushed or satin finishes. All grades available. Write for Bulletin B-2.

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For cutting down and coloring all metals. Ideal for fully-automatic buffing machines. Keeps buffs cooler on high-speed runs. Write for Bulletin B-3.

AHCO BURNISHING COMPOUND B
For burnishing aluminum or brass. Produces a smooth, bright finish, free from stain or attack. Write for Bulletin B-4.

AHCO CUTTING COMPOUND 17-D-4
For deburring or cutting down steel or iron parts in tumbling barrels. Prepares surfaces for chemical treating or organic finishing. Write for Bulletin B-5.

AHCO WATER DISPLACING COMPOUND
For removing water from metal surfaces. Produces unspotted, dry surface. Oil type for special applications also available. Write for Bulletin B-6.

These products are manufactured under the same rigid laboratory control that has made AHCO Compounds, AHCOLOID Metal Cleaners, and 99% Nucast Nickel Anodes outstanding for uniform high quality wherever metal finishing is performed.

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Branch News

color slides, the various phases of exposure testing, and the facilities for inland, salt atmospheric, tidewater, and total immersion testing, as well as such special tests as the termite cabinet (termitarium), soil burial, etc.

Members of other Branches are cordially invited, as well as executives of manufacturing concerns, who may be vitally interested in the rapid predetermination of permanency and durability which is made possible by the utilization of the constancy of the sub-tropical climate of southern Florida.

To start things right, this will be a dinner meeting, at a place famous for its excellent cuisine, and at a very moderate cost. Those who cannot attend the dinner are nonetheless welcome for Mr. Deneen's talk at about 8:30. Make your dinner reservations early by mailing a check, and indicate your preference for fried chicken, broiled lake trout, or French fried shrimp.

Time—Friday, September 12, 7:00 P.M.
Place—Finger's Restaurant
4981 Plainfield, N. E.
Dinner—$3.00 per plate
Reservations:
Mr. R. O. Blackford
1336 Calvin, S. E.
Grand Rapids, Mich.

KENNETH HAMPEL, *Secretary*

JACKSON-LANSING BRANCH

The April meeting of the Jackson-Lansing Branch was held at the Meadow Lark Inn, Jackson, Mich.

The 29 members present enjoyed an excellent fish dinner and refreshments of the amber liquid variety.

PRESIDENT W. H. MOGLE called on SECRETARY FRED STUCKENBERG to present the annual financial report. We learn, while the treasury is not exactly bulging, that the branch is in good financial condition. The report was adopted as read.

R. W. REDMOND was given an enthusiastic vote of thanks for his very successful direction of the social event of the year. Many wish to have the ladies' night meeting made an annual affair.

After rather spirited balloting in the election of a new board of managers, the following became the newly elected officers:

President—R. W. REDMOND
First Vice-President—HAROLD MARSH
Second Vice-President—JOE HOEFER
Third Vice-President—ULO FORSYTH
Secretary-Treasurer—WILLIAM MOGLE
Librarian—LARRY HENDERSON
Assistant Librarian—EDWARD BOSCA
Board of Managers—DR. D. T. EWING, MILLS DRAKE, FRED STUCKENBERG, C. DEGROAT
J. H. HOEFER, *Publicity Chairman*

LOS ANGELES BRANCH

At the regular meeting of the Los Angeles Branch on May 14, an exceptional talk on "Research in Aircraft Processing" was given by MR. WILLIAM CASTELL, Lockheed Aircraft Corporation, Burbank, Calif. Since the Aircraft Industry occupies such a prominent position in the metal finishing shops of the area, the data given by Mr. Castell proved interesting and informative to the large audience in attendance.

Mr. Castell commented that excellent corrosion resistance was obtained by thin coatings of a fused cadmium-tin plate on steel with the thinness of the coating helpful in the fitting of precision parts. Plating the part with cadmium first, then tin, and fusing together gave more uniform results than trying to plate an alloy of this nature.

Magnesium requires special care in processing, or trouble is encountered with adhesion on bending and metal bonding. Precleaning is important, and excessive times in alkaline cleaners should be avoided. The best results were obtained by using the chromic acid-sodium nitrate bright dip. Hydrofluoric acid dips tend to give better results than the acid fluoride salt dips, but short immersion times of under one minute in the hydrofluoric acid should be observed for maximum adhesion of the coating formed on the part in the boiling dichromate solution. Mr. Castell also commented on some of the troubles encountered in shipping magnesium from the mills, and suggested that all shipments be protected by careful packing. To prevent corrosion during shipping and storage periods, he said, the parts should be treated at the point of origin by the Dow No. 1 method plus oil.

On aluminum, anodizing seems to still

The usual pickling acids are dangerous—both for those who handle them, and in storage. Their fumes can do real damage to nearby equipment. And they are strong in their action—with ever-present danger of excessive acid action on the parts being treated.

Use a Safe, Quickly Dissolved SOLID!

Magnus D-Scale-RS is a perfect substitute for liquid acids.

IT IS SAFE **. . . because it is shipped in chemically inert crystalline form. You dissolve it quickly and easily in water to make the working solution. Even then it does not give off corrosive fumes . . . and does not present a hazard to operators.**

IT IS EFFECTIVE **. . . because it removes the rust and scale you're after, in either hot or cold solution. At the same time it is inhibited to prevent attack on the metals being cleaned. And Magnus D-Scale-RS can be used in barrel work just as effectively as in tanks.**

If you're using liquid acids in any volume for descaling or derusting, write for Bulletin 36. It will open your eyes to real economies and improvements in your operations.

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CLEANERS • EQUIPMENT • METHODS

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NEW FEDERATED ZINC ANODES

...Better Than Ball Anodes...No Flash...No Gate...No Voids

Make your plating job easier by using Federated Zinc Anodes, the smooth zinc anodes that won't catch or stick when you drop them into the container.

These anodes are round on top, flat on the bottom . . . scientifically designed and cast in an open mold to give you a smooth-finish anode without voids or inclusions.

The material used for Federated Zinc Anodes . . . special high-grade zinc and no scrap . . . and Federated's known superiority in production combine to make these anodes the best on the market.

To order or to obtain further information on Federated Zinc Anodes or on any other anodes for the plating industry, call or write any one of Federated's 22 sales offices across the country. There is one near you.

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Only Automatic Centerless Bias Buffs

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New dip processes are available which produce results superior to the more common chromadizing solutions, and in some cases superior to anodizing, at reduced costs, thereby replacing anodizing in many instances.

Hard anodizing films up to .002 inch thick, produced in a patented sulphuric-oxalic acid bath require much lower batt temperatures and higher current densities than normally used.

Mr. Castell concluded his talk with a short discussion on Titanium.

The discussion period which followed indicated the audience had enjoyed the talk, had gained information from it, and that Mr. Castell's work and dissemination of this information was greatly appreciated.

EARL W. ARNOLD,
Secretary

LOS ANGELES BRANCH

The discussion for the meeting of June 4 centered around three speakers and their papers, which were originally given at the Buffalo convention in 1951.

These speakers were: GLEN BECKWITH, Metallon Products, Inc., whose paper was "Requirements of Zinc Base Diecastings for Electroplating"; EARL W. ARNOLD, L. H. Butcher Company, whose paper was "Chemical and Electrochemical Preparation of Zinc Base Diecastings for Electroplating". In the absence of CHESTER G. BORLEF, United Chromium, Inc., STUART KREUTEL gave the paper entitled "Electroplating Zinc Base Diecasting".

The papers were presented in a short resume form and the meeting was then open for general discussion. Considerable interest was expressed since diecastings present many problems in nearly all plating shops.

One point which was brought out by Mr. Beckwith was his experience in stripping chrome, nickel and copper from zinc base diecastings with an 85 per cent orthophosphoric acid solution operated at room temperature and a current density of approximately 3 amperes per square inch with an impressed voltage of 20–40 volts. His experience has been that there is no etching of the diecastings and the parts can be rinsed thoroughly and then reprocessed without any trouble.

EARL W. ARNOLD, *Secretary*

MELBOURNE BRANCH

On the 15th of May, the Melbourne Branch eclipsed all previous activities by holding a "Special Afternoon and Evening Conference" at the Federal Hotel on the subject of "Current Alternatives to Nickel Chromium Plating". The magnificent attendance of approximately 160 members (including 15 from Interstate Branches), visitors and guests, proved the popularity of the conference, but at the same time soberly reflected the growing significance of the current nickel shortage in this country.

The seven papers scheduled were given by experts in their own particular fields, and were concerned with Bright Zinc (theoretical and practical) Colourless Lacquers, Direct Chromium Plating and Periodic Reverse Copper. It was evident from the discussion and the papers read that Bright Zinc Direct Chromium and P. R. Copper were contributing to the relief of an electroplating trade suddenly cut off from a regular nickel supply.

MR. ANDREWS stated he was not overimpressed with tin-nickel plating, seen on his recent visit to England. The extremely toxic nature of the fumes evolved was a serious drawback. Nevertheless, in his opinion, the coating was suitable for spittoons and similar articles. The evergreen MR. E. WRIGHT, of Sydney Branch, held sway a number of times, and it was later established that he had revealed a trade secret during one of his anecdotary orations.

All the papers delivered and most of the information arising from the discussion periods will be published in the Defence Research Laboratories' journal, "Plating Notes".

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A short speech by Branch President H. Merton, followed by congratulations to the Branch from Mr. B. Armstrong (Sydney Branch) brought the technical sessions to a close. Supper was served.

C. E. Naylor,
Hon. Secretary-Treasurer

MELBOURNE BRANCH

The 70th regular meeting of the Branch, held on June 19, was attended by 51 members and visitors.

The resignation of Secretary Clive Naylor was received with regret and Bruce Pearce was elected as his successor. After a well received motion of thanks to the retiring secretary, Hugh Pearce appropriately introduced Clive as the speaker for the evening, his subject being "Electro-polishing".

The speaker introduced the subject with a clear and comprehensive summary of the mechanism theories of electro-polishing followed by a survey of its application in the fields of decorative finishes, engineering processes, preparation for plating, inspection and metallography. Clive, who has contributed largely to the development of electropolishing techniques in Australia, illustrated his interesting talk with a large number of clear and informative slides.

B. Pearce, *Honorary Secretary*

MONTREAL BRANCH

The Montreal Branch reports the following officers elected to serve for the 1952–1953 fiscal year:

President—G. R. King
First Vice-President—J. J. Roche
Second Vice-President—William Feeley
Secretary-Treasurer—J. T. Reisenburg, Jr.
Librarian—P. M. Coady
Board of Managers—R. E. Gordon (Chairman); G. R. Davidson; J. D. Fairbairn, B. T. Kelly, J. T. Reisenburg, Sr.

John T. Reisenburg, Jr.,
Secretary

PITTSBURGH BRANCH

The Pittsburgh Branch held its Annual Ladies' Night Banquet on Saturday night, April 19, at the well known Mona Lisa Lounge with a record attendance of over 300. A sumptuous one-pound T-bone steak covered with mushrooms and surrounded by all the trimmings was greatly enjoyed by everyone.

After dinner, Entertainment Committee Chairman, Paul McCloskey, presented outgoing President, Bob Wootter, with his past-president's pin. Bob then announced that one of our members, Herb Saylor, had been given the distinction of being made an honorary member of the Pittsburgh Branch. The ladies were each given a perfume atomizer as a favor and several Westinghouse appliances were presented as door prizes. Cigars, courtesy of Schaffner Brothers, were given to the men as an after dinner treat.

Slim Bryant and his orchestra entertained us with dance music. When the party finally broke up everyone agreed that our get-togethers are growing better every year.

R. H. Schindler, *Secretary*

SAGINAW VALLEY BRANCH

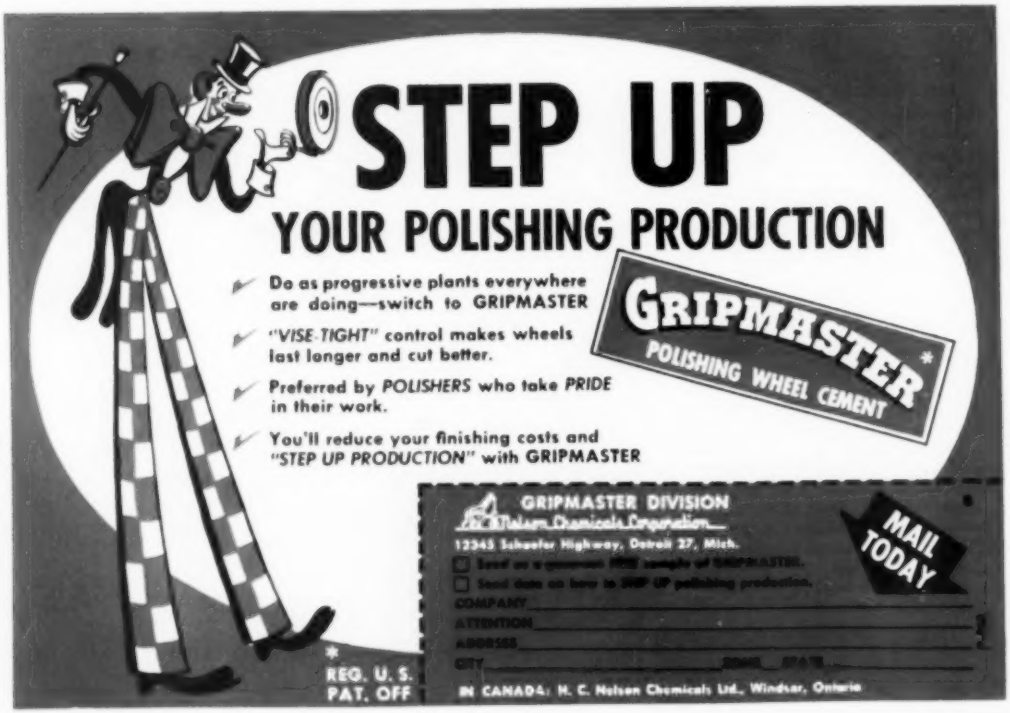
Forty members and guests attended the May 14th meeting at Zehnders Hotel in Frankenmuth, Mich.

Our new President, Mr. L. Membiole, opened the meeting and Mr. E. Brisson introduced the speaker for the evening, Mr. Henry Harrison of Oakite Products, Inc., who gave us some food for thought with his interesting talk on "Plant Waste Disposal". This was followed by a question-and-answer session.

One new member was elected to the Society, Mr. L. Bellinger of the Behr-Manning Corporation.

The door prize was donated by Mr. Rockwell of the Klaeber Manufacturing Company.

D. Wm. Snyder, *Recording Secretary*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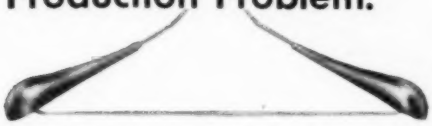

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Branch News

SAN FRANCISCO BRANCH

The May meeting was called to order by PRESIDENT PATTENGER at 8:30 P. M., then turned over to MR. CHESTER BOSLET, our guest speaker. His subject covered the practical aspects of conversion coating of zinc and cadmium plating. Copies are available from the secretary upon request. Our second speaker of the evening was MR. R. C. PUMPHREY of the U. S. Department of Commerce who gave a short talk on information of practical plating and research available to platers. For those of us who are interested we may contact him at: U. S. Department of Commerce, Office of Technical Services, Flood Building, San Francisco, Calif.

The business session of the meeting included the election of a new member, JOHN M. O'BRIEN. Meeting adjourned 11:45 P. M., 25 members and visitors attending.

HORACE J. SMITH *Secretary-Treasurer*

SOUTHEASTERN BRANCH

At the April meeting of the Southeastern Branch, the following members were elected to serve as officers for the coming year.

President—M. E. AWTREY
First Vice-President—E. P. COFIELD
Second Vice-President—BAYNARD SMITH
Librarian—C. H. HORNER
Secretary-Treasurer—W. T. WEYMOUTH

Our May meeting will definitely be held in Jacksonville, Fla. Our good friend, GEORGE W. TAYLOR, is making all arrangements.

W. T. WEYMOUTH,
Secretary-Treasurer

SOUTHEASTERN BRANCH

The last regular meeting for the summer was held at the Georgia Hotel, Friday, June 6. The meeting was called to order at 8:00 P. M. with nine members present, M. E. AWTREY presiding.

One application was read and accepted, MR. RAY CHARLES STEFFEY, of Chattanooga, Tenn.

Our speaker for the evening was our good friend and member, BAYNARD R. SMITH of American Lava, Chattanooga. Mr. Smith gave a very interesting talk on the plating of ceramics, and at this time invited the branch to hold its October meeting in Chattanooga, at which time he would arrange a shop visitation for all attending. The branch accepted his invitation so that our October meeting will be held in Chattanooga. Mr. Smith is to make all necessary arrangements and send out notices to that effect.

Regular monthly meetings will resume on the second Friday of September at the Georgia Hotel.

The meeting adjourned at 9:30 P. M.

WM. T. WEYMOUTH,
Secretary-Treasurer

SYDNEY BRANCH

The 83rd general meeting of this branch was held at the Trust Building, corner King and Castlereagh Streets, Sydney, on Thursday, 12th of June, with an attendance of 20 members.

A discussion on the Melbourne Conference held in May was given by four of our members who attended. MR. J. MURPHY discussed the visit from the time they were wholeheartedly welcomed on their arrival, the different plant visitations, the inspection of the Collingwood Technical College, and passed praise on our delegates who attended this Conference.

MR. B. ARMSTRONG gave a summary of the technical papers presented. He said that the subject matter of the papers was timely, and well presented with a lively and interesting discussion. He gave some details of the discussion including ERNIE WRIGHT'S discourse on the bronze plating of Mum's electric iron. He concluded by saying that the organization of the 1953 Conference was in capable hands, but there was much work still to be done and he appealed for the cooperation of every member to ensure the success of the Conference.

MR. MILLWARD described the plant visitations picking out certain points which he thought would be of some interest to the members.

MR. LEAN then said that with the

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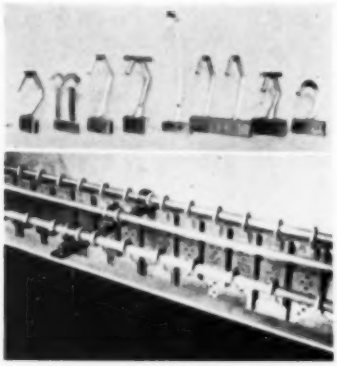

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Branch News

ground covered by the previous members there was not much left to talk about, but nevertheless he passed on the experiences that he took part in.

In our Question Box period Mr. BAKER required the solution for a jet black finish on copper. Mr. HOPKINSON said that 1 lb caustic soda to a gallon water, with reverse current of 3 amps per square foot, should give good results.

B. BRIDGEMENT, *Secretary-Treasurer*

SYRACUSE BRANCH

The May meeting of the Syracuse Branch was held at the Moose Hall, Syracuse, N. Y., with 46 members and guests present. A pre-meeting dinner of baked stuffed pork chops was served the members who arrived early.

A Round Table discussion of Plating Problems was presided over by KEN PARNELL with a panel of experts from the Syracuse Branch answering the questions. Both the experts and members-at-large gained from this meeting which proved to be one of the best of the year.

A movie, "Onondaga Out-of-Doors", was shown by a local sportsmen group. Refreshments were served through the courtesy of PHIL JACQUES of the Beacon Supply Company.

The Clam Bake Committee was appointed with Ken Parnell as chairman, BILL PHILLIPS and ART MARTINEAU, SR., as co-chairmen.

LINDLEY S. WOOD, *Secretary*

WATERBURY BRANCH

The Waterbury Branch held its final meeting of the year on Thursday, April 24, in the Colonial Room of the Hotel Elton.

WILLIAM GRAY, one of our charter members, installed the officers for the coming year as follows:

President—E. V. COLLINS
Vice-President—FRANCIS EDDY
Second Vice-President—PERRY SLOAN
Secretary-Treasurer—SPENCER HENN
Assistant Secretary—ARTHUR TRACY
Librarian—HARRY STREATER
Assistant Librarian—EDWARD GARLAND
Publicity Chairman—WARREN MAXWELL
Board of Managers—EARL COUCH, D. MAITLAND, G. HISERT

ROBERTA DUBPERNELL of the Naugatuck Chemical Division, United States Rubber Company, Naugatuck, Conn., reviewed work done on the subject of Hydrogen Overvoltage by herself and DR. GEORGE DUBPERNELL of United Chromium, Inc. The paper suggested that hydrogen overvoltage is not due to hydrogen at all, but to the electrodeposition of minute traces of alkali metals such as sodium.

The history of the subject was reviewed, and it was shown that the new point of view is useful and agrees with observations in many fields.

C. W. MAXWELL, *Publicity Chairman*

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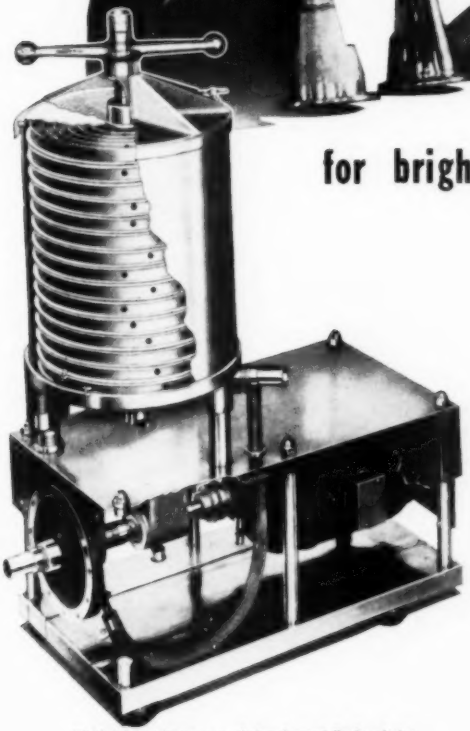

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Membership Report of the A. E. S.

Elections

BUFFALO: Charles Malkasian, Henry McConnell

LOUISVILLE: Charles R. Arbeguet, Henry T. Brumdeve, Jr., Albert S. Engle, Richard E. Hafer, Walter B. Haines, Jr., W. A. Nelson, Charles H. Peters, Raymond W. Shallcross, Millard E. Vowels

MELBOURNE: Francis D. Carroll, Donald McMillan, Evan C. Rowe, Alexander A. Wasley

NEW YORK: Augustus DiPasquale, James H. Ewing, Isidore Friedman, Francis H. Haley, Howard Heller, Harry J. Martin, Thomas A. Mobile, Sr., Daniel W. Paris, Charles Pep, Rhodes W. Polleys, Joseph H. Roening, Culey A. Taylor

PROVIDENCE-ATTLEBORO: Richard C. Ashley, John Gaboury

SYDNEY: Kevin John Jones, Frederick J. Strong

TOLEDO: Angelo J. Caputo, Daniel Caputo

Reinstatements

SYRACUSE: A. David Douglas, Hubert H. Langenmayer

TOLEDO: John Stegeman

Transfers

A. R. Waters from Buffalo; James J. Keers, Jr., from Syracuse; John H. Leever from Waterbury.

Resignations

CLEVELAND: Jack E. Kern

LOS ANGELES: George H. Boeck, Charles Green, Virgil Scamanna

SYRACUSE: John G. Benson, C. M. Bosworth

Suspensions

BUFFALO: P. J. Conn, J. J. Fusco, J. E. Hanson

NEW YORK: A. Havcock, Richard Mozer

SYDNEY: L. Aldridge, A. Bruce, W. Eastwood, L. Miller, G. Olson, G. Potts, A. M. Reeves, J. C. Shepherd, K. D. Stewart

SYRACUSE: Walter A. Carey, John H. Dowling, Robert W. Hergenson, Joseph A. Leo, Theodore L. McGinn

Membership Competition

BRANCH	Membership Apr. 1, 1952*	New Members	Net Change in Membership	Per Cent Net Change
First Group				
Toronto	132	7	+ 7	+ 5.3
New York	305	17	+16	+ 5.2
Melbourne†	168	8	+ 7	+ 4.8
Milwaukee	145	8	+ 6½	+ 4.5
Cleveland	212	10	+ 8½	+ 4.0
Chicago	469	17	+14½	+ 3.1
Philadelphia	203	4	+ 3	+ 1.5
Newark	240	3	+ 3½	+ 1.5
Grand Rapids	155	3	+ 2	+ 1.3
Bridgeport	154		+ ½	+ 0.3
Pittsburgh	132	5		
Boston	140	..		
Detroit	500		− 1	− 0.2
Los Angeles	218	1	− 3	− 1.4
Hartford	148	2	− 2½	− 1.7
Second Group				
New Haven	88	6	+ 7	+ 8.0
Cincinnati	80	4	+ 5	+ 6.3
Montreal	72	3	+ 3	+ 4.2
St. Joseph Valley	74	2	+ 2	+ 2.7
Baltimore-Washington	96	3	+ 2½	+ 2.6
Indianapolis	114	3	+ 2	+ 1.7
Dayton	81	3	+ ½	+ 0.6
Waterbury	115		+ ½	+ 0.4
St. Louis	102			
Saginaw Valley	71			
Providence-Attleboro	92	2	− 1	− 1.1
Buffalo‡	107	2	− 1½	− 1.4
Syracuse	104	5	− 2	− 1.9
Rochester	88	4	− 2	− 2.3
Rockford	79	1	−16½	−20.9
Third Group				
Louisville	24	9	+ 9	+37.1
Dallas-Fort Worth§	69	11	+11	+15.9
Western Ontario	19	2	+ 2	+10.5
Southeastern	47	6	+ 4½	+ 9.6
Toledo	39	2	+ 3	+ 7.7
Springfield	55	3	+ 3	+ 5.5
Twin City	66	3	+ 3	+ 4.5
San Francisco	67	3	+ 3	+ 4.5
Lancaster	67	4	+ 2	+ 3.0
Jackson-Lansing	59	1	+ 1	+ 1.7
Adelaide	58			
Columbus	54			
Allentown-Reading	44			
Houston	40			
Hamilton	22			
Outside Competition				
Kansas City		34	+34	
Wichita		19	+19	
At Large	125			
In Transfer	23			
Total A. E. S.	5,748	224	+149½	+ 2.6
Active Membership, May 31, 1952				5,897

*Subject to correction. †, ‡, §Winners in first, second and third group, respectively, of 1951-1952 membership competition.

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40 Thames Street, New York 6, N. Y.

Secretary ..... The Executive Secretary

ADELAIDE, AUSTRALIA meets second Wednesday of each month. Address G.P.O. Box 598E, Adelaide, S. A., Australia.

ALLENTOWN-READING meets third Wednesday of each month in Spurgeon's Hotel, Allentown, Pa. Secretary-Treasurer, Lee C. Wetring, 526 N. St. Elmo Street, Allentown, Pa. Research Finance Committee Chairman, William R. Pfeiffer, Jr., 975 Green Street, Allentown, Pa.

BALTIMORE-WASHINGTON meets second Tuesday of each month with meetings in Baltimore at the Engineers' Club and in Washington, D. C., at the National Bureau of Standards. Secretary, Asaf A. Benderly, 1829 Summit Place, N. W., Washington 9, D. C.

BOSTON meets first Thursday of each month in Hotel Statler. Secretary, Dr. George P. Swift, 53 Galen Street, Watertown 72, Mass. Research Finance Committee Chairman, Louis V. Gagnon, 53 High Street, Natick, Mass.

BRIDGEPORT meets second Friday of each month in Barnum Hotel. Secretary-Treasurer, Gerald B. Rice, 367 Granfield Avenue, Bridgeport 8, Conn. Research Finance Committee Chairman, Carl Schaefer, c/o Casco Products Corporation, 512 Hancock Avenue, Bridgeport 5, Conn.

BUFFALO meets first Friday of each month in Markeen Hotel. Secretary and Research Finance Committee Chairman, B. P. Fortin, Jr., 209 Forest Drive, Orchard Park, N. Y.

CHICAGO meets second Friday of each month at 8 P. M. at Western Society of Engineers, 84 E. Randolph Street. Secretary-Treasurer, Paul Glab, 882 N. Paulina Street, Chicago, Ill. Research Finance Committee Chairman, William B. Johnson, c/o Industrial Filter & Pump Manufacturing Company, 5914 Ogden Avenue, Chicago 50, Ill.

CINCINNATI meets fourth Wednesday of each month at 8 P. M. in Engineering Society Headquarters, McMillan Street and Woodburn Avenue. Secretary, Charles Wise, c/o The Buckeye Products Company, 7020 Vine Street, Cincinnati 16, Ohio.

CLEVELAND meets first Friday of each month in Hotel Carter at 8 P. M. Secretary-Treasurer, A. J. Lupien, 4408 Carnegie Ave., Cleveland 3, Ohio. Research Finance Committee Chairman, John D. Little, c/o The Harshaw Chemical Company, 1945 E. 97th Street, Cleveland 6, Ohio.

COLUMBUS meets first Friday of each month at 8 P. M. in Battelle Memorial Institute Auditorium. Secretary-Treasurer, John Soderberg, 40 W. Long Street, Columbus, Ohio. Research Finance Committee Chairman, Fred Brune, R. D. 7, Marion, Ohio.

DALLAS-FORT WORTH. Secretary-Treasurer, A. C. Fricke, 1415 Plowman Avenue, Dallas 8, Texas.

DAYTON meets first Friday of each month in Engineers Club. Secretary, Harry Brown, 516 Boulevard, Dayton 9, Ohio. Research Finance Committee Chairman, Robert L. Ruleff, 1002 Broadview Boulevard, Dayton 9, Ohio.

DETROIT meets first Friday of each month in Hotel Statler. Secretary-Treasurer, Joseph Gurski, 8885 Littlefield, Detroit 28, Mich. Research Finance Committee Chairman, Bruno Leonelli, 238 Rhode Island, Highland Park 3, Mich.

GRAND RAPIDS meets second Friday of each month at 7:30 P. M. in Rowe Hotel. Secretary, Kenneth Hampel, 138 Elwood Street, Grandville, Mich. Research Finance Committee Chairman, Harold Grutter, 1222 Gladstone Avenue, S. E., Grand Rapids, Mich.

HAMILTON BRANCH meets third Thursday of each month in the Conference Room, West End Plant, Canadian Westinghouse Company, Ltd. Secretary, H. Fallowes, c/o Electroplating Division, Steel Company of Canada, Canada Works, Hamilton, Ontario, Canada.

HARTFORD meets third Monday of each month in Hotel Bond. Secretary, Stanley Platoz, 26 Erwin Place, New Britain, Conn. Research Finance Committee Chairman, Frank W. Smith, 46 Cottage Street, Meriden, Conn.

HOUSTON meets fourth Friday of each month at 7:30 P. M. Secretary-Treasurer, J. R. Byerley, Dixie Electroplating Company, 3001 Engelke Street, Houston, Texas.

INDIANAPOLIS meets first Wednesday of each month at Fox Steak House, 1207 E. Washington Street. Secretary, Edward Bruck, Platers Supply Company, 2311 Valley Avenue, Indianapolis 18, Ind.

JACKSON-LANSING meets second Tuesday of each month alternating between Meadow Lark Inn in Jackson and Porter Hotel in Lansing. Secretary-Treasurer, W. H. Mogle, 1623 Wildwood, Jackson Mich. Research Finance Chairman, J. H. Hoefer, 5440 Meridian Road, R.R. 6, Jackson, Mich.

KANSAS CITY—Secretary-Treasurer, Olin K. Bock, 5317 W. 58th Street, Mission, Kansas.

LANCASTER meets second Friday of each month at 8 P. M. in Thaddeus Stevens Industrial School. Secretary-Treasurer, Harry A. Saylor, 40 N. Poplar Street, Elizabethtown Pa. Research Finance Committee Chairman, Harry Hovis, Lincoln Highway, West Lancaster, Pa.

LOS ANGELES meets second Wednesday of each month at 6:30 P. M. in Rodger Young Auditorium. Secretary, Earl W. Arnold, 3628 E. Olympic Boulevard, Los Angeles 23, Calif. Research Finance Committee Chairman, Earl Coffin, 5102 Marburn Avenue, Los Angeles 43, Calif.

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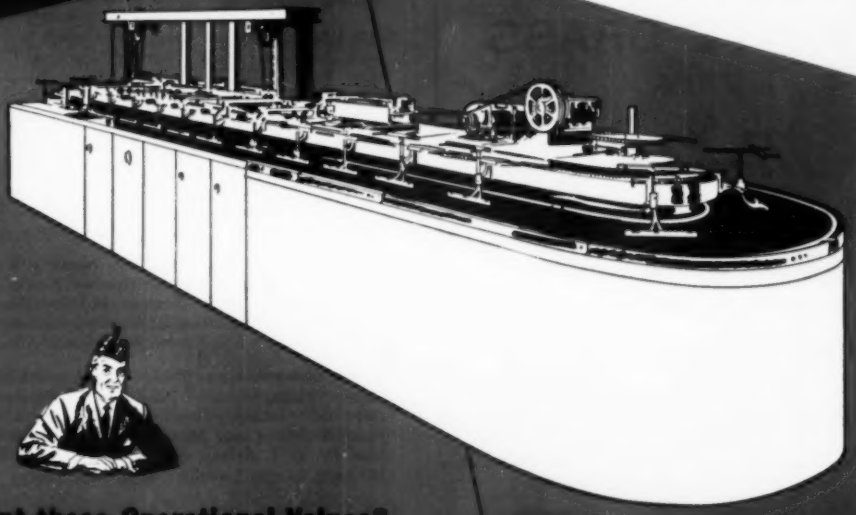

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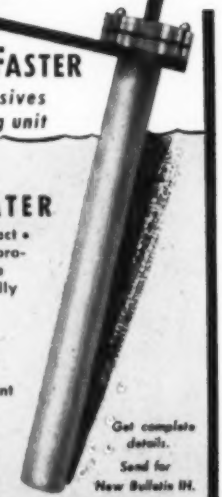

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MELBOURNE, AUSTRALIA meets third Thursday of each month at 8 P. M. in Metallurgy Theatre, Melbourne Technical College, 124 Latrobe Street. Honorary Secretary-Treasurer, S. B. Pearce, 55 Durham Road, Surrey Hills, E. 10, Victoria, Australia.

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NEWARK meets third Friday of each month at 8 P. M. in Hotel Robert Treat. Secretary-Treasurer, George Wagner, Hy-Grade Electro Plating Company, 35 Fourth Street, Newark, N. J. Research Finance Committee Chairman, Edwin Bowerman, 166-41 17th Avenue, Whitestone, N. Y.

NEW HAVEN meets second Tuesday of each month alternating between Sterling Chemistry Laboratory, Yale University, and Hotel Taft. Secretary-Treasurer, Clark A. Brown, 46 Loller Road, Hamden, Conn. Research Finance Committee Chairman, Dr. H. L. Kellner, c/o Lea Manufacturing Company, 16 Cherry Avenue, Waterbury 86, Conn.

NEW YORK meets second and fourth Fridays of each month in Statler Hotel. Secretary-Treasurer, George Schore, 150 Bennett Avenue, New York 33, N. Y. Research Finance Committee Chairman, George F. Hermann, 52 Chestnut Street, Brooklyn 8, N. Y.

PHILADELPHIA meets fourth Friday of each month in Harrison Laboratory Building, University of Pennsylvania, 34th and Spruce Streets. Secretary, I. William Marcovitch, 1434 Lardner Street, Philadelphia 24, Pa. Research Finance Committee Chairman, Robert H. Tiers, c/o Pennsylvania Salt Manufacturing Company, Box 4388, Philadelphia 18, Pa.

PITTSBURGH meets second Thursday of each month in the Avon Room of Sheraton Hotel. Secretary, R. H. Schindler, 125 Fairfax Road, Forest Hills, Pittsburgh 21, Pa. Research Finance Committee Chairman, S. S. Johnston, c/o Weirton Steel Company, Weirton, W. Va.

PROVIDENCE-ATTLEBORO meets third Monday of each month in Providence Engineering Society Hall, 195 Angell Street, Providence, R. I. Secretary, George A. Gibbs, 65 Farragut Avenue, Providence, R. I. Research Finance Committee Chairman, Pierre B. Lonsbury, 78 North Avenue, Attleboro, Mass.

ROCHESTER meets third Monday of each month at the Forty Over Eight Club, 933 University Avenue. Secretary, Charles B. Fideor, 180 St. Casimir Street, Rochester, N. Y. Research Finance Committee Chairman, Cecil Thornton, 20 Lafayette Parkway, Rochester, N. Y.

ROCKFORD meets second Monday of each month in Faust Hotel. Secretary, Kenneth Kieselburg, 419 Theodore Street, Rockford, Ill. Research Finance Committee Chairman, David Stockton, The Udylite Corporation, 1943 Walnut Street, Chicago 12, Ill.

SAGINAW VALLEY meets for dinner at 7 P. M. and meeting at 8 P. M. at Zenders, Frankenmuth, Mich., second Wednesday of each month, September through May except February. Secretary-Treasurer, G. L. Gutscher, Jr., 2512 Walter Street, Flint, Mich. Research Finance Committee Chairman, Alfred Knight, 113 S. Farragut Street, Bay City, Mich.

ST. JOSEPH VALLEY meets first Wednesday of each month at 8 P. M. in Hotel Elkhart, Elkhart, Ind. Secretary-Treasurer, Eugene Roth, 1720 Mishawaka Avenue, South Bend 15, Ind. Research Finance Committee Chairman, William McDowell, 211 Sycamore Street, Elkhart, Ind.

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SYRACUSE meets third Monday of each month in Loyal Order of Moose Hall, 643 W. Onondaga Street. Secretary, Lindley Wood, 1329 Bellevue Avenue, Syracuse 4, N. Y. Research Finance Committee Chairman, George W. Cavanaugh, 129 Kenwood Avenue, Syracuse, N. Y.

TOLEDO meets first Thursday of each month at Commodore Perry Hotel. Secretary, Gaston Bergeman, 703 Pine Street, Fremont, Ohio.

TORONTO meets second Friday of each month in Royal York Hotel. Secretary, Walter E. Mark, 761 O'Connor Drive, Toronto, Canada. Research Finance Committee Chairman, C. D. Short, 1281 Pape Avenue, Toronto, Canada.

TWIN CITY meets first Monday of each month, October through June, in the Covered Wagon (Lodge Room), 114 S. 4th Street, Minneapolis, Minn., with dinner at 7:00 P. M. and business and technical session at 8:00 P. M. Secretary-Treasurer, Robert L. Buckley, c/o Industrial Chemical & Equipment Co., 205 11th Avenue So., Minneapolis 15, Minn. Research Finance Committee Chairman, E. H. Lindemann, c/o Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.

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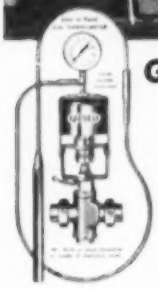

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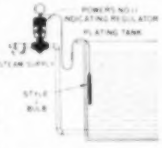

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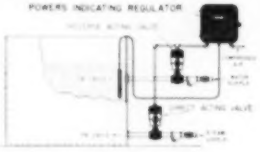

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AMERICAN CHEMICAL SOCIETY, 122nd National Meeting, Atlantic City, N. J., September 14–19.

MONTREAL BRANCH, A. E. S. Annual Banquet on October 2.

34TH METAL CONGRESS AND EXPOSITION, sponsored by the American Society for Metals in Philadelphia, Pa., on October 20–24.

ANNUAL MEETING OF THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS in Cleveland, Ohio, on December 7–10.

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